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BRITISH CHEMICAL ENGINEERING

A HEYWOOD TECHNICAL PUBLICATION

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DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

New H.Q. for Chemical Engineers

THE Institution of Chemical Engineers has now moved into its new premises—at 16 Belgrave Square, London, S.W.1, which is next door to the S.C.I. The accommodation at its disposal represents a great improvement over the Victoria Street premises, which the Institution occupied for some twenty years. For the first time in their history, the chemical engineers are now provided with an adequate library. At the reception at which representatives of the Press were given their first opportunity of inspecting the new headquarters, the Institution's president, Mr. J. A. Oriel, expressed gratitude to all who made the new headquarters possible. He specifically mentioned the industrial companies which provided the money that paid for the interior decoration—"a friendly gesture by firms intimately concerned with chemical engineering" was Mr. Oriel's expression. These firms were British Petroleum, Courtauld, Distillers Co. Ltd., Esso Petroleum Co. Ltd., I.C.I., Shell Petroleum Co. Ltd. and Unilever Ltd. He stressed the importance of chemical engineering to Britain, which must find ways of reaping the economic advantages of its brilliant scientific work, adding that the chemical engineers of this country must be as original as our research workers.

Monopolies Commission on British Oxygen

THE most emphatic conclusions yet reached by the Monopolies and Restrictive Practices Commission are printed at the end of its report "on the supply of certain industrial and medical gases". The commission considers that B.O.C.'s profits have been unjustifiably high for an almost complete monopoly facing a limited financial risk. Previously it states that in 1952-54 B.O.C. made 23-24% profit on capital employed, and cites the company as telling the commission that it regards 23-25% as a reasonable return and about the rate of profit required to support its modernisation and research programme. The commission's comment is that in order to maintain and develop its business a monopoly company in B.O.C.'s position does not need to earn the same return on capital as a company in a competitive industry, and it then proceeds to make the point that, instead of being below the general level, B.O.C. made a larger profit on capital employed in its gases business than was earned in manufacturing industries generally. (11-20% was the profit range for most manufacturing industries in the same period.) "It follows that the prices charged by B.O.C. for oxygen and dissolved acetylene are too high," says the report. The commission states that it lacks evidence on which to base any general finding that B.O.C. *costs* are too high.

Two members of the commission express disagreement with the majority view that B.O.C. profits are unjustifiably high, adding that they are impressed that so few B.O.C. customers have complained about prices being too high, regarding this as a sign of general satisfaction among the firm's customers. This minority statement ends with the suggestion that B.O.C.'s operations should be examined periodically by or on behalf of the Government to ensure that there is no abuse of the monopoly.

B.O.C.'s Reply

ANOTHER minority addendum by two other commission members, Mr. I. C. Hill and Sir Arnold Plant, deals with the risk of technical stagnation in this non-competitive industry and recommends that (*a*) B.O.C. price lists should be published regionally and be based on regional costs and (*b*) regional price lists should list an ex-works price plus a variable addition for delivery based on the cost of transport.

B.O.C. issued a Press statement which made the following main point, which we quote verbatim: "The company has found its earnings no more than sufficient to enable it to procure the capital in the open market necessary to maintain and develop its business under present-day conditions. The commission itself is not agreed on the appropriate rate of profit. Two members expressly find that the profits earned are not unreasonable."

The report contains valuable information on the manufacturing costs of oxygen (the main gas discussed by the commission) and on projected oxygen plants, as well as details about the consumption of the gas. Confidential reports to which the commission had access reveal that 1955 costs of gaseous oxygen for plants in the 100-250 tons per day output range, vary from 2s. 7½d. to 2s. 2d. per 1000 cu. ft: of gas. Liquid oxygen, however, which is obtained from much smaller plants costs 5s. 11d., half of which is the cost of electrical power, for the same quantity of gas. Compressed gas is much more expensive—an average figure is 15s. per 1000 cu. ft. Delivery costs for liquid and compressed gas amount to 9.3 and 23.5% of the total cost of production.

New Tonnage Oxygen Plants

THE report provides a comprehensive list of tonnage oxygen projects. This includes the 100 tons-a-day plant at Margam for the Steel Company of Wales, and the 200 ton plant which B.O.C. plans to erect as part of the same project. The 200 ton B.O.C. "Rescol" plant at Scunthorpe will supply oxygen to the individual steel works in the neighbourhood. Butterley is providing I.C.I. with a 240-ton plant at Billingham which is due to produce in 1957; most of the oxygen will be used to make synthesis gas for ammonia manufacture. At Middlesbrough B.O.C. is erecting a 200 ton "Rescol" plant as part of a project which will supply oxygen to the local steel works and nitrogen to the local chemical works. B.O.C. is to erect tonnage oxygen plants for Consett Iron and Richard Thomas & Baldwins Ltd. Shell Refining & Marketing Co. Ltd. will have a B.O.C. "Rescol" plant (240 tons a day capacity) at Shell Haven to supply oxygen for ammonia

manufacture, and Shell Chemicals Ltd. has placed a contract for a "Rescol" tonnage plant at Partington, to be used in connection with ethylene oxide production (by direct oxidation of ethylene).

Calder Hall Honours

ONLY two men connected with Calder Hall received awards in the New Year's Honours List, and this fact has led to some rather bitter comments among technologists, who feel that the powers that be and that decide who shall receive honours are still labouring under the misapprehension that industrial atomic energy is something organised from Harwell. Possibly the remark most apposite for this occasion was the one coined by the man who received a knighthood for his contribution to Calder Hall, Mr. William Leonard Owen (the Director of Engineering, A.E.A. Industrial Group); he said some time ago "It is a lot of bunk talking of atomic energy as so many people do in the Press and elsewhere as if it was something exclusively scientific". The editor of the London Gazette should note this for future reference.

The other recipient of a "Calder Hall" honour was Sir Christopher Hinton. Before they joined the atomic energy project Owen and Hinton had worked together on the explosives side of the Ministry of Supply. Then, as now, Owen was Hinton's director of engineering. In the second half of 1945 they were concerned with the running down of the filling factories, and both were due to leave the Ministry and return to I.C.I. when they had completed this job. An unexpected 'phone call from the Minister of Supply, Mr. Wilmot, upset their plans completely. He invited them both to remain with the Ministry and take on the building of atomic energy factories, an invitation which prompted Owen to throw at Hinton his classic question "What the hell is atomic energy?"—a question that Hinton found beyond him at that time. Between them they have provided a very convincing answer, and all within one decade.

Ziegler Polythene at Partington

SHELL CHEMICAL's plant at Partington, which will produce a thousand tons of Ziegler low pressure polythene a year, should come on stream this spring. Shell have already made samples of Ziegler polythene available to fabricating firms for trial, and has issued preliminary data about the properties of its product. Initially the grades available are restricted to three, but other varieties may be added later.

According to Shell Chemical's technical bulletin on low-pressure polythene, tests on stress-cracking characteristics show the material to be more resistant than the more conventional polythenes and that its chemical resistance is generally better. Ageing tests indicate, however, that Ziegler-type polythenes are subject to some degree of oxidation. To overcome this, specific antioxidants need to be incorporated into the polymers, but antioxidant-free grades can be supplied. The addition of about 2% carbon black provides additional protection. Shell Chemicals suggest the following applications for its product; tubing and piping, industrial mouldings, wire and cables, film for packaging, coating of paper, fabrics, metals, etc., bottles and sterilisable equipment, domestic holloware and household articles, toys, chemical plant equipment, and fibres.

In the U.S.A. seven big low-pressure polythene plants are being erected which are due to start producing this year. Their total production capacity will amount to some 400 million lb. (In 1956, U.S. output of polythene came to about 500 million lb.) Among these seven plants will be three Ziegler units each with a capacity of 30 million lb. The plants that will work the Phillips low-pressure process all have a larger capacity; the biggest unit will be the 110 million lb. plant of Phillips Chemicals Company at Pasadena.

Cracking Pipes

EVERYONE is wanting to find out just how good pipes of low-pressure polythene are, following the note in *Chemical & Engineering News* which said that "pipe made from Ziegler low-pressure product in Germany is developing cracks after use for even cold water". That led to Hercules (who have a "know-how" agreement with Hoechst, the German producers of Ziegler polythene) issuing a statement to the effect that no commercially installed pipe made from Hoechst's material had ever failed. The fact remains however that Hoechst have not yet found it possible to give the kind of guarantee which the German pipe manufacturers wish to obtain as to the length of life they can expect from polythene piping. Moreover, Hoechst admit that they are now busy improving their polythene to make it more suitable for piping purposes. This question of durability is important even in the case of domestic piping, in which field polythene may eventually find considerable application. For agricultural piping high-pressure polythene has proved eminently suitable.

N.C.B.'s Underground Gas Project

THE National Coal Board have appointed Sir Alexander Gibb and Partners, in association with Messrs. Cremer and Brearley, to act as their consultants in carrying out the development of underground gasification. Humphreys and Glasgow Ltd. have been appointed the main contractors for the engineering work. On present plans, a pilot scheme should be in operation by the end of 1958. Gas will be delivered to a 5 megawatt generating plant, which will be built by the Central Electricity Authority. Newman Spinney, near Barlborough on the border of Yorkshire and Derbyshire, has been chosen as the site for the pilot scheme. The coal seam chosen for gasification is of secondary quality and is not worth mining because of its high ash content. The country has considerable reserves of coal of poor quality and it is hoped that underground gasification may provide a means of using this national resource. Some 5000 tons of coal have already been gasified in a series of experiments conducted by the Ministry of Fuel and Power and the National Coal Board.

Expansion in Chemical Production

PRODUCTION of general chemicals, drugs and pharmaceuticals, and plastics materials continued to expand notably during 1955, according to the first results of the Census of Production for that year just issued by the Board of Trade. Of general chemicals the "gross output" (a value subject to an "element of double counting") was £383.3 million—an increase of 13.6% over the 1954 figure. By comparison the increase over the years 1951-1954 was 26.5%. In 1955, £143 millions' worth of drugs and pharmaceuticals were produced, an increase of 14.4%, compared with an increase for the period 1951-1954 of 40%. Plastics production rose by 20.5%, to £100.2 millions (1951-1954,

+ 40%). Paint and varnishes rose in production by 3.4% to £121.2 millions' worth, and the production of soap, candles, and glycerine fell by 3% to £98.1 million. Included under the Ministry's heading "chemicals and allied trades" is mineral-oil refining. As the rapid expansion in this large industry was checked during 1955 (production levelled off at just over £300 millions' worth) the overall expansion in the chemicals section of industry was, on the Board's reckoning, no greater in 1955 than that for industry as a whole. It would be unfortunate indeed if the administrative division adopted by the census authorities led to a wrong impression of the health of the chemical industry gaining currency. During 1955, 2.2 times more operatives than other employees were engaged in the chemical and allied trades. The number of operatives grew to 288,900 (an increase of 2.6% over the previous year) and that of other employees to 129,700 an increase of 4%. Since 1951 the wages and salaries bills of the two groups have increased by respectively 42% and 43%.

Deferment of Engineering Graduates

INDEFINITE deferment of National Service will be granted to university graduates who complete courses of study in 1957 and who have first-class honours degrees in a main branch of science or engineering, if they take up employment in Britain requiring a science or engineering qualification of degree standard. The existing deferment schemes for scientists and engineers apply mainly to graduates employed on urgent work of high priority and in science teaching in schools, and to a few graduates employed in fundamental research. The decision to extend deferment was announced in the House of Commons by the Minister of Labour, Mr. Iain Macleod. It follows representations made to him some months ago by the F.B.I.

Plant for Synthetic Rubber

THE first plant in Britain to produce synthetic rubber in quantity was commissioned at the Dunlop Rubber Co.'s site at Fort Dunlop, Birmingham, recently. The production is experimental, and on the modest scale of 1500 tons of rubber a year. Most of the product will be of the "general purpose" type required for tyres, but a range of new rubbers will also be made as they are developed by Dunlop's central research division. The manufacturing technique adopted is similar to that in use at Polymer's Sarnia co-polymer unit (see p. 64), yet the plant has been designed so that the process may be modified easily to incorporate new developments. Supplies of the raw materials butadiene and styrene will be obtained from oil refineries in Britain. The plant is highly mechanised, covers 11,000 sq. ft. and has cost £600,000. One of its functions is to provide sufficient material to enable large-scale service trials of synthetic rubbers to be conducted.

The New Science Library

AT a conference held by the Library Association in London recently, Dr. D. J. Urquhart of the DSIR invited scientists to submit suggestions on the design and organisation of the National Lending Library for Science and Technology, with the planning of which the DSIR has been charged. So far, the plans are still fluid except for a decision that the library should be created as soon as possible, and now is the time to ventilate ideas. The purpose of the library will be to help users of scientific literature and bibliographical organisations to obtain the literature which is not available locally. The library will take over from the Science Museum Library some literature and the responsibility for providing a lending service. It will be located outside the London area, and the lending service will be by post. Among the problems which arise in planning the library, Dr. Urquhart said, were how should the future world-output of scientific literature, and the future demand for literature be estimated; how widely would photocopies and micro-forms be used, and how would new techniques including data processing be best employed. There was general agreement that the library must be planned for at a least a century ahead.

After making several assumptions, Dr. Urquhart came to the conclusion that by 2057 the library may have to hold 12-18 million volumes, perhaps one quarter in Chinese, and that the site plan should provide for this material to be stored and issued in the traditional form. He thought that the volume of inter-library lending and the demand on the new library was likely to increase more rapidly than the increase in volume of world literature.

Emphasising that, in Britain, we must not only collect scientific literature of the world, but must see that it is used, he said that a first-rate scientific library should attract first-rate scientists. Unfortunately, that does not happen automatically in science. The scientist has at his disposal laboratories which seem more exciting than book stores, and apparatus more intriguing than bookshelves. Somehow we must seek to change this. We must give good scientists a glimpse of the library problem from the inside. Perhaps this could be done by creating "readerships" and by having laboratories in the new library concerned with developing suitable techniques for handling the growing volume of information. Scientists, he suggested, were necessary to study the flow of information. Unless something were done, he said, the application and progress of science might be in danger of being restricted by our inability to handle the growing volume of existing knowledge.

A New Kind of Technological Institute

THE need for establishing self-supporting specialist post-graduate and research schools within British technological institutes was emphasised by Dr. B. V. Bowden, principal of the Manchester College of Science and Technology in a speech at the annual meeting of the College's Court of Governors recently. Great Britain was particularly poor in schools for highly specialised technologies such as paper making and polymer chemistry, in fact, there was only one establishment where paper making could be learnt—the Manchester College. Yet in the U.S.A., he pointed out, it was established practice for Institutions to be attached to Universities for providing, for example, four-year post-graduate courses leading to Ph.D. degrees in such specialist studies as paper-making and plastics technology. An important aspect of those courses was that most of the students were paid out of the proceeds of research work undertaken by the institutes for the government or industry. The establishment in Britain of schools undertaking sponsored research would accord well with the principle of close liaison and cross-fertilisation of ideas between technical institutes and industry, which are the corner-stones of the future system of technological education which Dr. Bowden described in his recently published book. Moreover, self-supporting schools would attract staff having the necessary practical experience, in so far as salaries comparable with those in industry and commensurate with the responsibilities could be paid.

There exists in this country at present only a limited amount of technological skill, and if, as was suggested at a conference on the expansion of technological education, organised by the National Union of Teachers, in London last month, industry must be persuaded somehow to "share the cake" with teaching institutions, this is how the sharing might be done, with immediate advantage to both parties.

Forthcoming Conferences and Courses

CHEMICAL Reaction Engineering will be the subject for discussion at the twelfth meeting of the European Federation for Chemical Engineering to be held in Amsterdam, over the period May 7-9. The five session's of the symposium will be devoted to, respectively, general considerations; transport phenomena in heterogenous reactions; non-uniform concentration distributions; reactor efficiency and reactor development. Papers will be read by Prof. D. W. van Krevelen, Prof. M. Letort, Prof. H. Kramers, Prof. E. Wicke, Dr. J. G. van der Vusse, R.A.T.O. Nysing and Prof. H. Kramers, Prof. P. V. Danckwerts, Dr. K. Rietema, Dr. H. Hofmann, Prof. K. G. Denbigh, Dr. C. van Heerden, Dr. A. P. Oele, Prof. K. Schoenemann, F. Schnur, K. Traenchner and Dr. A. Klinkenberg. Applications to attend the meeting should be sent to the symposium's secretary, Dr. K. Rietema, 23, Driftweg, Huizen (N.H.), Holland.

A symposium on the scaling-up of chemical plant and processes is to be held at Church House, Westminster, London, S.W.1 on May 28 and 29, under the sponsorship of Het Koninklijk Instituut van Ingenieurs (chemical Engineering Group); de Koninklijke Nederlandse Chemische Vereniging (section for Chemical Technology); The Society of Chemical Industry (Chemical Engineering Group), and The Institution of Chemical Engineers. Thirteen papers dealing with the theoretical, practical and economic aspects of scaling-up will be read. Information on how to obtain copies of the papers or attend the symposium may be obtained from The General Secretary, The Institution of Chemical Engineers, 16, Belgrave Square, London, S.W.1.

A series of one-week courses on the oil-firing of boilers is to be held during 1957 by the National Industrial Fuel Efficiency Service. They will be suitable for works engineers and boiler house superintendents, and will be held at the organisation's premises at Reading, commencing on the following dates: April 8, May 13, and June 17. A course will be held in Belfast commencing on March 25. The syllabus will include the characteristics and storage of coal tar fuel, gas, diesel and fuel oils; the conversion of boilers and plant to oil firing; and the control and maintenance of oil burning equipment. The fee for the course is £7 10s., and enrolment forms are obtainable from N.I.F.E.S., 71, Grosvenor Street, London, W.1.

Development in Scottish Chemicals

EXPANSION in plant and development laboratories is recorded in the recently published report of the Scottish Agricultural Industries for 1956. The largest sulphur-burning contact sulphuric acid plant in Scotland, which has been erected on the company's site at Leith (*Brit. Chem. Eng.*, 1956, 1, 147), commenced operation in July, some weeks in advance of the planned date. All of the company's production of sulphuric acid, now centred at Leith and Aberdeen, is based, therefore, on the use of elemental sulphur. In this method S.A.I. has confidence in view of present price levels of sulphur, and the adequacy of supplies from the U.S.A. and from Mexico, where workings have been extended greatly. After two years' operation the Research and Development laboratories at Leith are to be extended by the addition of a third storey. During the year under review pilot plant for work on fertiliser manufacture was constructed and brought into use on a site adjoining the laboratories. Basic slag production at the company's Skinningrove, Yorkshire, plant was a record, and the combined production of the Skinningrove and Scunthorpe works was double that of the previous twelve months. Sales of fertilisers and agricultural lime were higher than in the previous year despite price increases that reflect rises in the costs of raw materials. The consumption of nitrogen by Scottish farmers showed an "outstanding" increase. In support of the view that a continuance of that trend would be profitable to farmers it is reported that ICI have found, in a study of 40 dairy farms whose profits greatly exceeded average values, that those farms consumed five times as much nitrogen, four times as much potash and one-and-a-half times as much phosphate per acre of grassland as did an average farm.

GUIDE TO PUMP SELECTION

THE two-part article on the selection of pumps for the chemical and process industries (*British Chemical Engineering*, 1956, Vol. 1, 298-305, and 361-368) has been published in reprint form. Copies of the reprint may be obtained from: The Circulation Manager, Drury House, Russell Street, London, W.C.2. Remittance (1s. 6d. per copy, post free) must accompany the order.

New Uses for Platinum

PRIMARILY to provide technologists with information on developments in the use of platinum and associated metals, Johnson Matthey, who have been connected with the production of platinum since 1817, have started the publication of a quarterly periodical entitled *Platinum Metals Review*. Articles in the first number, which is of 36 pages, deal with the protection of chemical process-equipment, catalysis, thermocouples for high temperature, cathodic protection of ships, and the deposition of metals. Grouped under headings are abstracts of technical papers and notes on new patents. In an illustrated article Dr. J. M. Pirie outlines the use of platinum metals for bursting discs in chemical plant.

To obtain discs which will burst at an unvarying pressure, he points out, it is necessary to make them of an exact thickness, and to be able to control the metallurgical properties of the material. By skilful workmanship it is possible to produce foil from which discs can be manufactured that will burst within 5 per cent. of the chosen pressure. The metal is affected, however, during use by corrosive attack, and the material may creep if the pressure is near the bursting point, and may suffer fatigue if fluctuating pressures are applied. All these factors tend to lower the bursting pressure and so to cause discs to fail prematurely in the range of normal working pressures. Platinum, he continued, had a high melting point and annealing temperature and "excellent" resistance to the effect of creep at temperatures up to about 400° C. Its resistance to the effect of stress-reversals was also adequate for service in bursting discs.

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Safety in the Chemical Industry

IT is about time that the old phrase "as safe as houses" was altered to something like "as safe as factories". Far more accidents occur in British homes than happen in British factories, and many more workers are injured during their travel to and from work than are hurt at their place of employment. We were prompted to think about safety problems by the lecture which Dr.-Ing. Siegfried Balke recently gave in London, under the auspices of A.B.C.M., on safety in the chemical industry.

As Dr. Balke pointed out, the chemical industry has a good safety record. He cited German figures showing that the incidence of accidents per unit of production is lower for chemicals than in iron and steel manufacture, mining, quarrying, woodworking and the building industry. The same thing is true in Britain. According to the latest annual report of the Chief Inspector of Factories (for 1955, published by HMSO, 1956, Cmd. 8), the accident frequency rate in the case of chemicals is only 1.43 as against 2.79 for metal production, 1.53 in engineering works and 2.55 in saw mills and general woodworking. Very few industries—e.g., textiles with a frequency rate of 1.29—can provide a lower figure.

It is interesting to take the salient points of Dr. Balke's lecture, which drew very heavily on German experience, and to consider how British methods and achievements in this field compare with those of Germany. At the outset, it is essential to realise that the two countries have a different approach to safety problems. The difference is fundamental and very obvious, a fact which is reflected by the following comment, published recently in the *Transactions of the Institution of Chemical Engineers* (1956, Vol. 34, No. 3, p. xliii):

"*Safety*. Compared with the English chemical industry, there was a very noticeable lack of safety regulations in the German chemical industry. No effort appears to be made to provide guards on moving machinery or to prevent accidents caused by the splashing of corrosive liquids. The German managements are content to rely on the common sense of the more highly trained worker." (This quotation comes from P. L. Graham's impressions collected during the visit of the Graduates and Students section to German chemical factories last summer.)

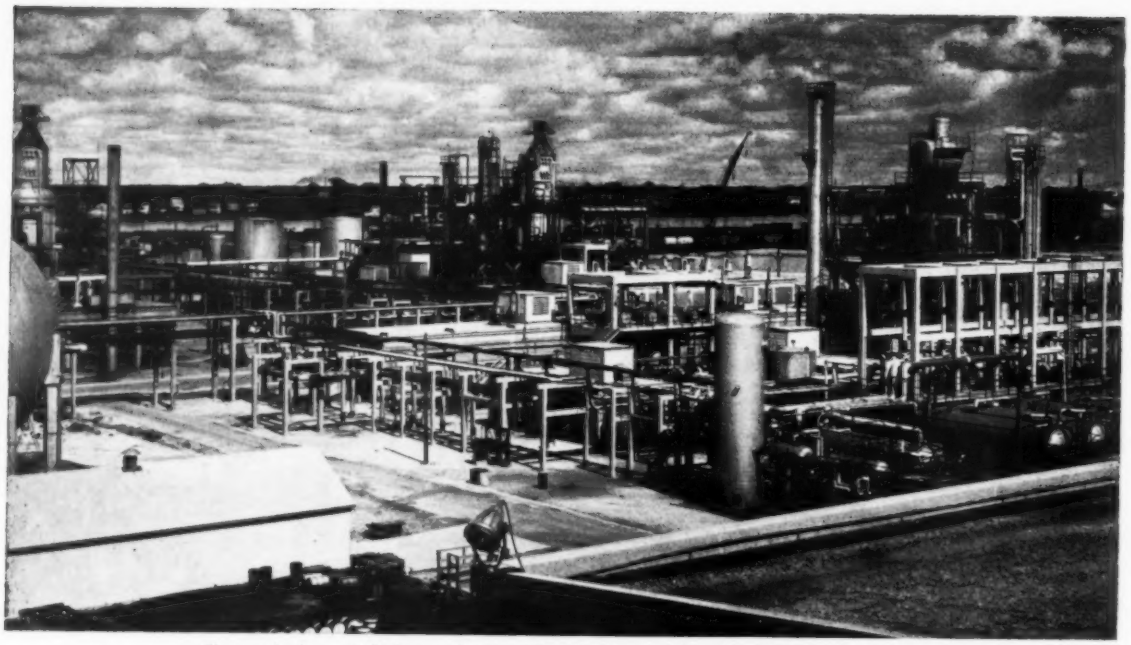
Dr. Balke opened his lecture by saying that the concept that problems of industrial health and safety are merely an extension of technical works management and are mainly concerned with occupational hazards is out of date. Most informed people would agree with this comment, and with his next remark—that today works safety must be regarded as a primary interest of top management. This seems to us to be a thoroughly sound ideal, which is probably favoured by most progressive employers, regardless of nationality. We believe that in the British chemical industry many managements operate a safety policy which matches that ideal. In Germany this ideal is still rather remote from practice.

The works safety regulations, and the way those regulations are enforced, vary from country to country. The ideal may be the same, but practice differs. As Dr. Balke stressed, it differs according to the political and economic structure of the particular country, as well as its historical traditions. These factors account for the big differences which separate Britain and Germany, for example. A strong democratic system of government is in the British tradition; as a result, when the national conscience was aroused by the conditions that were created by the Industrial Revolution, Britain became the world's pacemaker in the field of factory welfare and factory legislation. Another factor of great importance was the early establishment of collective bargaining between employers and workers. A separate factor, less easily defined but which certainly cannot be neglected in this context, is the fact that in Britain the employer can appeal to the worker's sense of self-discipline.

The Germans have a quite different set of traditions to reckon with; the difference between the two countries can be briefly summed up as the difference between democrats and authoritarians. The whole history of Britain's factory inspectorate demonstrates the magnitude of the improvements in factory conditions which are possible by means of *persuasion* in a democratic country. In Germany the accent has been on *regulation*; for example, industrial accident insurance was made compulsory by German law in 1884, and the improvements which followed that step were achieved more by regulations and compulsion than by persuasion.

The hard economic facts that are relevant to this subject were emphasised by Dr. Balke. For instance, he stressed the fact that, on the average, every works accident in Germany causes the loss of about twenty working days. He made it quite clear that he favours the collection of fuller statistical data showing the economic effect of absence from work owing to accident, though it is probable that in Britain the collecting of further statistics may not be worth while. We wonder how many British safety experts would agree with his suggestion that it is necessary to teach workers that "an accident is not just a bit of bad luck for a workmate or the fault of the works, but that the incident might endanger their own security of employment".

Everyone will agree with Dr. Balke's final comments. He spoke of the new hazards which accompany the introduction of new processes. In the past, the risks have been realised and remedied only after accidents have occurred. Now the need is to develop anticipatory measures to prevent accidents and industrial diseases.



General view of Polymer Corporation's plant at Sarnia, Ontario, Canada.

SYNTHETIC RUBBER AT SARNIA

Processes undertaken at the Polymer Corporation's installation at Sarnia, Canada, with details of the large energy consumption in the production of synthetic rubber are given in this article

by D. D. LIVINGSTONE and D. E. McLELLAN

THE first synthetic rubber plant to be built in the British Commonwealth, and still the only completely integrated plant of its kind in North America, is situated at Sarnia, Ontario, Canada. Its owners, Polymer Corporation Ltd., were incorporated on February 13, 1942, two days before Singapore fell to the Japanese, and they immediately commenced designing a plant that would produce annually 34,000 long tons of butadiene-styrene copolymer rubber and 6,700 long tons of butyl rubber. Nineteen months later, on September 29, 1943, the first synthetic rubber was produced on the Sarnia site. The site had been chosen because of the availability of suitable hydrocarbon feedstocks, the abundance of low-temperature water from the St. Clair River, the proximity of rubber goods manufacturers, and local port facilities for boat shipments. Financed and owned by the Canadian Government, the plant was operated by a group of private companies during the war and for a short time after, who supplied technical knowledge and plant management for a fee. After the war Polymer Corporation took over operations from them.

From the original annual output of 34,000 long tons of general-purpose butadiene-styrene copolymer rubber and of 6,700 long tons a year of butyl rubber, the plant's production has steadily increased to over 80,000 long tons a year of 15 different grades and types of butadiene rubbers and latices, and over 20,000 tons a year of six different grades of butyl rubbers. The plant consists of polymerisation units for making butyl rubber and butadiene-styrene copolymer rubber integrated with units for making the principal monomers (butadiene, styrene and isobutylene) used in production. It can be divided into the following:

(1) feed preparation units;
(2) butyl rubber unit;
(3) butadiene units;
(4) styrene units;
(5) copolymer unit; and
(6) steam and power plant.

Feed Preparation Units

Gaseous and liquid hydrocarbon streams from three adjacent refineries form the raw materials for the production of synthetic rubber. These streams, mainly from catalytic cracking units, are mixtures of low molecular-weight paraffins and olefins along with hydrogen sulphide mercaptans, carbon dioxide, carbon monoxide, nitrogen and hydrogen. From these streams the feed preparation units separate ethylene for styrene manufacture, isobutylene for butyl rubber manufacture and normal butylenes for butadiene manufacture.

The first feed preparation unit, the light ends recovery unit, recovers by fractionation a commercial ethylene stream and a C_4 cut containing the normal butylenes, isobutylene and butanes. The refinery streams are first

scrubbed with diethanolamine to remove hydrogen sulphide and carbon dioxide, and are dried in fixed-bed alumina-gel driers. After compression and chilling, the feed enters an absorber and a series of fractionating columns which separate the following fractions;

(*a*) a methane and "lighter" fraction used as plant fuel gas;

(*b*) a commercial ethylene stream;

(*c*) an ethane stream, which is thermally dehydrogenated in tubular furnaces to yield additional ethylene;

(*d*) a propane-propylene cut, which is added to plant fuel gas or returned to the refineries;

(*e*) a C_4 cut, for further processing; and

(*f*) a C_5 cut, which is returned to the refineries.

Because of the low boiling-points of the hydrocarbons processed, some 3000 tons of refrigeration have to be used in these separations.

The C_4 cut from the light ends unit along with extra C_4 cut from adjacent oil refineries is next processed in the isobutylene extraction unit to recover a high-purity isobutylene stream for butyl rubber production. The extraction is effected with a two-stage counter-current system using sulphuric acid. The acid, acting as a catalyst, hydrates the isobutylene to tertiary butyl-alcohol which dissolves in the acid phase, and is separated from the rest of the hydrocarbons.

The unreacted hydrocarbons (normal butylene and butanes) are washed with caustic soda and water to remove any acidic materials, and are then transferred to storage for further processing. The acid extract, containing the tertiary butyl-alcohol, enters a bubble-cap column where open steam at low pressure dilutes and heats the acid to reverse the hydration reaction to regenerate the isobutylene. The mixture of isobutylene, alcohol and water, distilled from the top of this column, is washed with caustic soda and with water to give high-purity isobutylene. Alcohol, recovered in the wash water, is concentrated in a small fractionating column and is then returned to the regenerating column where it is all converted to isobutylene. The dilute acid from the bottom of the regenerating column is concentrated under vacuum for re-use.

The unreacted hydrocarbons (all normal butylenes, normal butane and isobutane) from the isobutylene unit are next processed in the butylene concentration unit. Here, an extractive-distillation process recovers a commercial-purity normal butylene stream, leaving a butane stream which is returned to the refineries. A preliminary fractionation removes any polymers formed in the isobutylene unit, then the butylene-butane mixture enters a series of three columns acting as one fractionator. These columns, up to 165 ft in height, are the largest at the plant and provide a total of 165 trays. Acetone as a solvent is added near the top of this system to reduce the volatility of the normal butylenes and to increase that of the butanes, thus making the separation possible. The normal butylenes and solvent from the bottom of the column are separated in another column by normal fractionation. Both the butylene and the butane streams are washed with water to remove traces of solvent and this wash water, along with part of the main solvent-stream, is fractionated to maintain the acetone concentration and remove condensation products. Thus each of the three feed preparation units produces one of the primary feed stocks ethylene, isobutylene and normal butylene.

Butyl Rubber Plant

Isobutylene from the isobutylene extraction unit is polymerised along with a little isoprene to form butyl rubber. Fresh isobutylene is dried by fractionation, and is fractionated further to remove small amounts of normal butylenes and polymer. This purified feed is mixed with small amounts of isoprene, which is copolymerised with the isobutylene, in the presence of methyl chloride as an inert diluent. The mixed feed is chilled with ethylene refrigerant to below −130°F, and enters the reactors where aluminium chloride, dissolved in methyl chloride, catalyses the reaction and causes the polymer to form as solid particles of butyl rubber. These particles, suspended in methyl chloride, flow into a flash tank where hot water vapourises the methyl chloride and unreacted isobutylene and isoprene, leaving a slurry of butyl crumbs in water. The crumbs are then screened, pressed and dried to remove all moisture, formed into a continuous sheet by extrusion and milling, cooled,

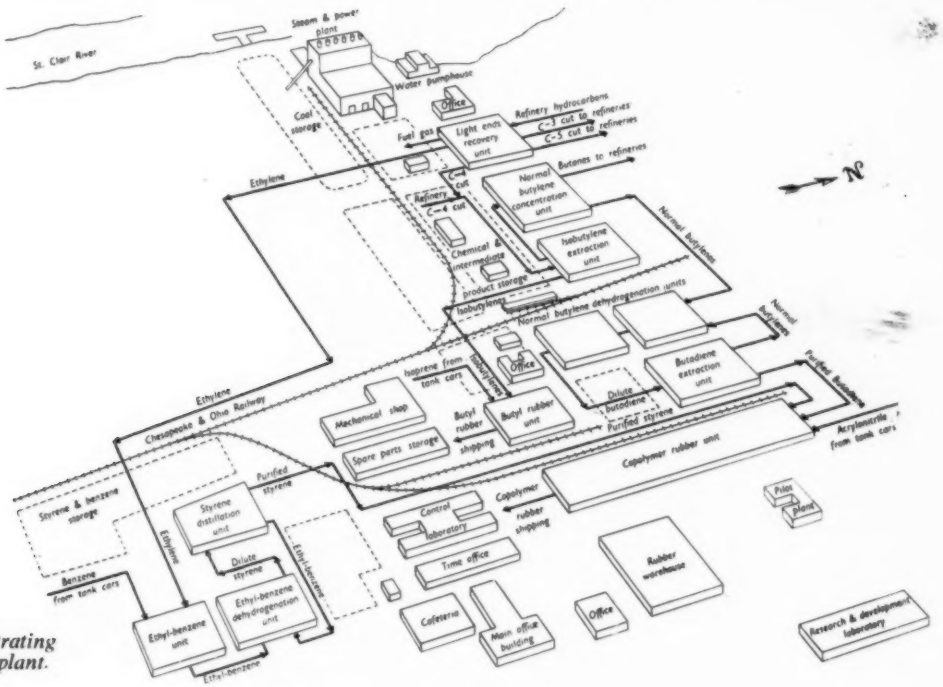


Fig. 1. Diagram illustrating material-flow through plant.

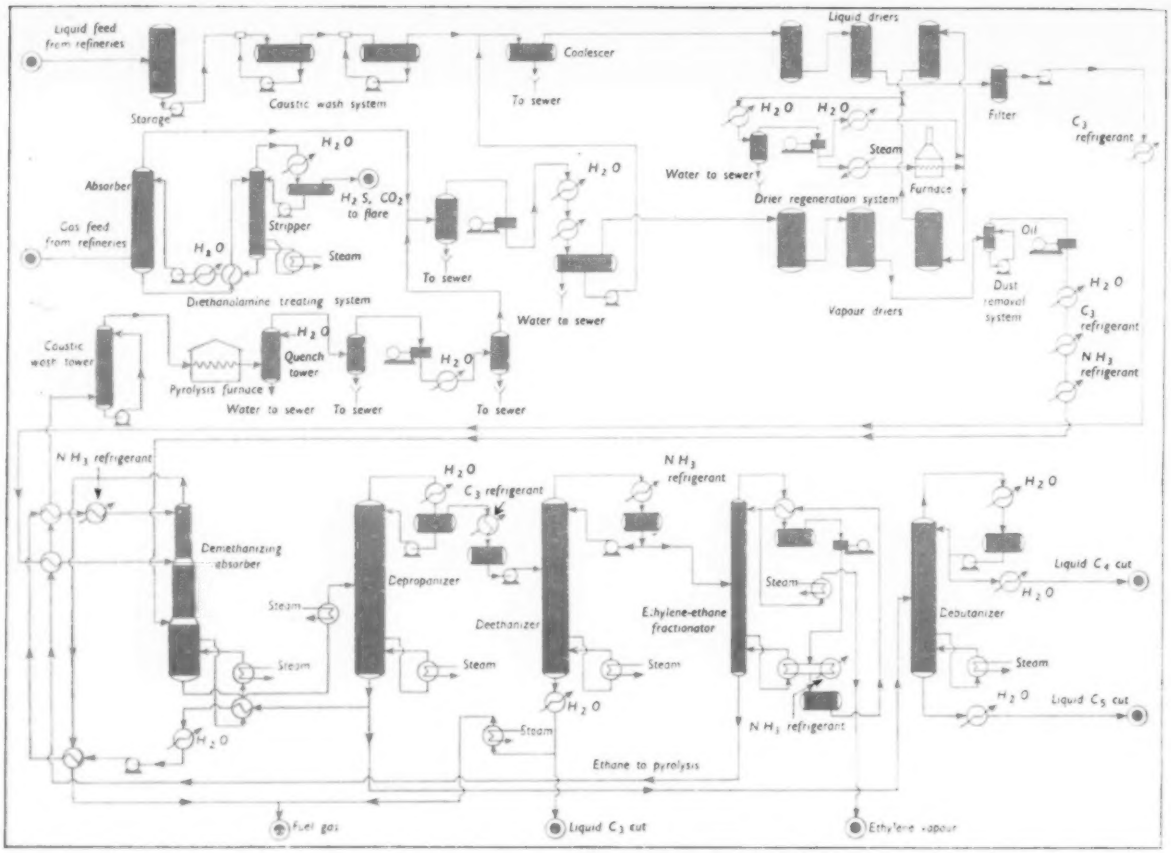


Fig. 2. Flow diagram of the light-ends recovery unit.

formed into rolls, and are then packaged for shipment.

The vapours from the flash tank are cooled, compressed, dried in alumina-gel driers, then fractionated in a series of columns to recover methyl chloride and unreacted isobutylene and isoprene. Recovered high-purity methyl chloride is used for catalyst make-up, and the remaining methyl chloride and the unreacted isobutylene is used as feed. The remaining recovered materials leave the system as two purge streams — one of low-purity isobutylene, which is returned to the isobutylene recovery unit, and the other of low-purity isoprene, which is discarded.

Butadiene Units

Normal butylenes are catalytically dehydrogenated to 1,3-butadiene in two parallel dehydrogenation units, and the dilute product from these units is concentrated in a solvent-extraction unit to produce high-purity butadiene. In each unit normal butylenes are heated to 1000°F, mixed with several volumes of superheated steam at 1300°F and passed over a calcium-nickel-phosphate catalyst in a reactor where some of the *n*-butylene dehydrogenates to butadiene and hydrogen. A small part of the feed is converted to light hydrocarbon gases and another part to coke, which deposits on the catalyst. The installation of two reactors in each unit permits operation of one in dehydrogenation service while the other is being regenerated by passing superheated steam and air over the catalyst to burn off the coke. A cycle timer automatically changes the service of each reactor periodically to keep the catalyst free of carbon.

The hot reactor-product gases are cooled in waste heat boilers, an oil quench tower, water-cooled exchangers, and a water quench tower to condense and remove the steam. The remaining hydrocarbon gases are compressed and fractionated to remove the C_3 and lighter gases for use as fuel gas, and the C_3 and heavier liquids for use by the refineries. The C_4 fraction, containing by weight 20 to 25% of butadiene, is next concentrated in the butadiene extraction unit to produce polymerisation-grade butadiene.

Butadiene is recovered from the dehydrogenation product by low-temperature extraction using a cuprous-ammonium-acetate solvent in a series of counter-current mixers and settlers. The butadiene-free C_4 cut remaining is washed with water to recover any dissolved solvent and then returned to the dehydrogenation units. The rich solvent is stripped of butadiene in a desorber column, then returned to the extraction section. The butadiene vapours from the desorber tower are washed with water to remove ammonia, compressed, fractionated to remove 1,2-butadiene and polymers, and are then pumped to the copolymer unit for synthetic rubber production. Ammoniacal water from the wash operations is fractionated to recover the ammonia. An impure recycle butadiene stream from the copolymer unit is also fractionated in the extraction unit to remove C_5 impurities and polymers.

Styrene Units

Styrene for synthetic rubber manufacture is produced by first reacting ethylene and benzene to form ethylbenzene. Then the ethylbenzene is dehydrogenated catalytically to produce styrene. The ethylene is obtained from the light ends recovery unit and the benzene comes from coke

plants of Canadian steel mills and from petroleum benzene plants in Canada and the U.S.A.

Ethylbenzene is formed by passing ethylene vapour through dry liquid benzene in the presence of aluminium-chloride catalyst and hydrogen-chloride promoter. The reaction product—a mixture of benzene, ethylbenzene, polyethylbenzenes, aluminium-chloride sludge and light tars—is settled to remove most of the aluminium-chloride sludge and, to remove the last traces, is washed with caustic solution. A series of fractionating columns recovers pure ethylbenzene and the benzene and polyethylbenzenes are returned to the reactor.

A superheated mixture of ethylbenzene and steam is passed over an iron-oxide catalyst at 1175°F to form styrene and hydrogen. The catalyst used also promotes the water-gas reaction so that almost all carbon formed is converted to gaseous products and the catalyst need be regenerated only once or twice a year. The reaction product—mostly styrene, ethylbenzene and hydrogen with small amounts of benzene, toluene and tar—is partially condensed to remove the hydrogen and light gases, which are then added to the fuel-gas system. The liquid portion is pumped to a fractionation unit for separation.

The fractionation unit operates under vacuum to lower the boiling points of the products and prevent polymerisation of the styrene. Sulphur is also added to inhibit polymerisation. The products are benzene, which is returned to the ethylbenzene unit; toluene, which is sold; ethylbenzene, which is returned to the dehydrogenation unit; tar, which is discarded; and high-purity styrene, which is used for synthetic rubber production or sold for polymerisation to polystyrene.

Copolymer Unit

The copolymer unit is the largest single unit of Polymer Corporation, both in area and in operating and maintenance staff. In it, butadiene and styrene are copolymerised in an emulsion polymerisation system to produce several varieties of butadiene-styrene copolymers. Acrylonitrile is also copolymerised with butadiene to make butadiene-acrylonitrile coplymers. The butadiene as received from the butadiene units contains 50 ppm of tertiary-butyl-catechol as a polymerisation inhibitor. This material is removed by a caustic soda wash followed by a water wash. Styrene and acrylonitrile as received are also inhibited, but it is not necessary to remove the inhibitor from these monomers before use.

The polymerisation reaction is carried out in 3100-Imperial-gallon glass-lined agitated reactors equipped with heat-transfer surfaces in the form of jackets or coils. The coolant is refrigerated calcium-chloride brine or cold water. The heat-transfer area and the coolant temperature required depend on reaction rate, polymerisation temperature and heat of polymerisation. Because of the several types of polymer produced, the reactors are divided into four groups, two groups on batch polymerisation and two on continuous polymerisation, each of the two continuous groups and one of the batch groups handling a different grade simultaneously. The other batch group is designed for speciality polymers, and handles several products at one time. Reactor instrumentation is designed for close measurement and control of polymerisation temperatures and quantity of materials charged.

All polymers produced are made by similar recipes, differences between types consisting of monomer ratio,

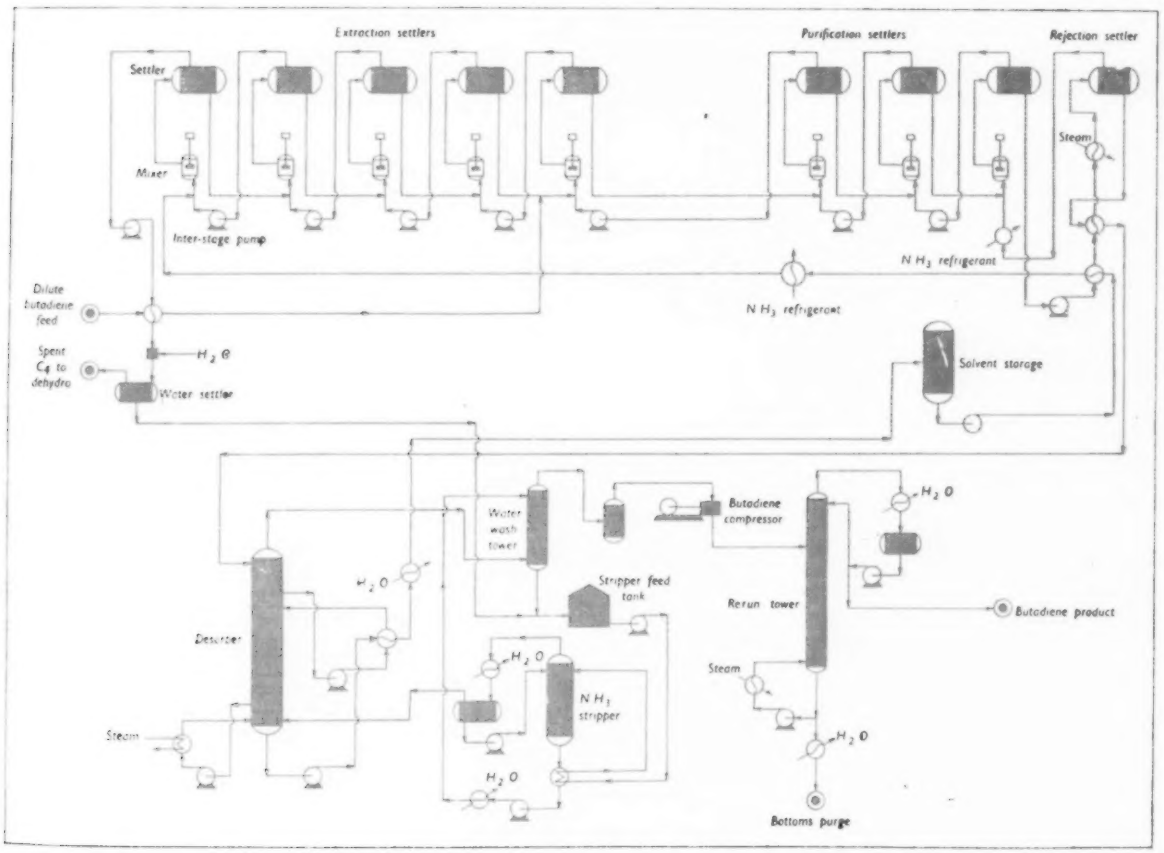


Fig. 3. Flow diagram of the butadiene-extraction unit.

polymerisation temperature, conversion and variations in the ingredients. The following materials are used in the emulsion polymerisation recipes in the copolymer unit:

Monomers. These are butadiene, styrene and acrylonitrile, and may be used in various proportions, depending on the end-use of the polymer.

Emulsifier. The emulsifier is used to make an oil-in-water emulsion of the monomers and may be fatty acid soap or resin soap, or combinations of these soaps, usually about five parts of total emulsifier per 100 parts of monomer.

Water. The quantity of water used varies from 100 to 200 parts per 100 parts of monomers. All water used in polymerisation reactions is softened before use to avoid the formation of insoluble calcium and magnesium soaps which would foul the heat-transfer surfaces of the reactors.

Modifier. This material is used in very small quantities to control cross-linking and molecular weight of the polymer. The modifier is usually a mercaptan in the C_{12} to C_{16} range.

Catalyst. Two types of catalyst are used, an organic peroxide for polymerisations carried out at low temperature (cold recipes), and an inorganic persulphate for polymerisations carried out at high temperature (hot recipes).

Activator. This is a complex of ferrous sulphate with a sequestering agent, and is used to control the reaction rate in cold recipes. The quantity used varies widely, depending on the reaction rate desired and the purity of the monomers. Activator is not required for hot recipes.

Shortstop. This material is added to stop the reaction when the desired monomer conversion level has been reached. The action of the shortstop is to destroy the catalyst and to terminate the growing of the polymer chains. To carry out both of these functions effectively it is necessary to use combinations of materials for short-stopping; usually sodium dimethyl-dithiocarbamate is included in the mixture.

Control of Processes

For batch polymerisation, the materials are measured into the reactors with the use of displacement meters; the catalyst and modifier, however, are weighed. For continuous polymerisation, the flow of materials through a chain of reaction vessels is measured and controlled with orifice meters, but the catalyst and modifier are measured by proportioning pumps. In both batch and continuous processes solid materials are charged as water solutions.

Reactor control is effected by determining, on samples of the reacting mixture drawn from the reactors, the percentage of solids and the viscosity of the polymer. The solids in any sample include the polymer and solid-charge ingredients, and the degree of conversion of the monomers to polymer can be calculated from the percentage of solids. The viscosity is determined by measuring the resistance to torsional stress of coagulated and dried polymer. It is an indication of the molecular weight and degree of cross-linking of the polymer. The instrument used for the determination is a Mooney plastometer, and the value measured is called the mooney. The mooney is also a primary specification for the finished product. To obtain the desired mooney, the reaction time is adjusted in batch polymerisation, whereas, in continuous polymerisation, the temperature is adjusted on the last few reactors in the

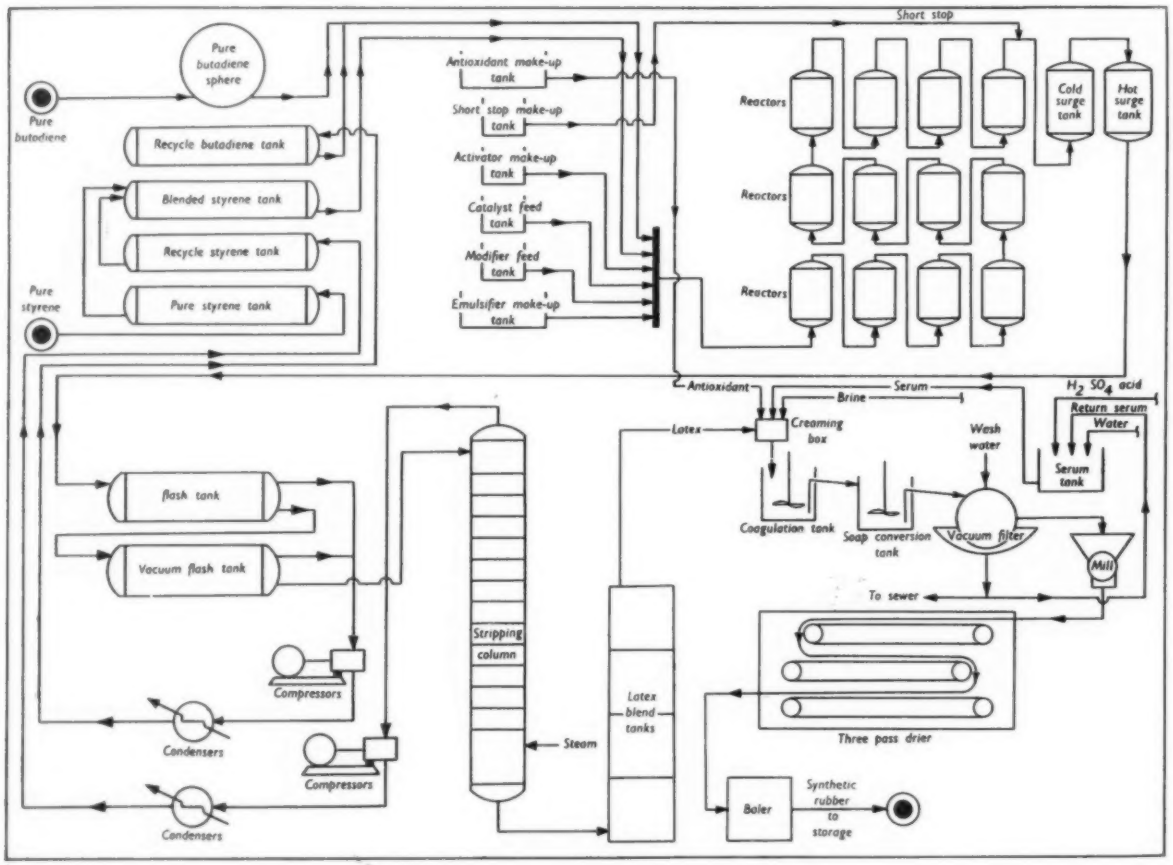


Fig. 4. Flow diagram of copolymer unit.

chain. If the mooney-conversion relationship comes out of balance the modifier level is adjusted.

The degree of conversion affects polymer properties and, for all polymers produced, the reaction is stopped short of 100% conversion. To make the process economically feasible and to permit further processing of the polymer, it is necessary to remove unreacted monomers, and this operation is carried out in the recovery section.

Handling of Latex

After the reaction has been stopped, the mixture of emulsified polymer, soap, water and unreacted monomer, now called latex, is dropped from the reactors into agitated blow-down tanks, where the latex is heated, by the addition of open steam, to a temperature at which most of the butadiene can be flashed off. The latex then flows through two flash-tanks, from which compressors draw off the unreacted butadiene as vapour, the first flash-tank being maintained at 1 p.s.i. gauge pressure, and the second at 160-200 mm. of mercury absolute. Compressed butadiene vapour is condensed and returned to the storage area. Part of it is recharged to the reactors along with fresh butadiene, and the remainder is returned to the butadiene units for purification. Latex from the second flash-tank is pumped to the top of a 9-ft diameter, 50-ft stripping-column containing twelve perforated plates. Steam is introduced to the column, styrene is steam distilled, condensed with the steam and continuously decanted and returned to the monomer storage area. There it is blended with fresh styrene and re-charged. Steam consumption is approximately 1.2 lb./lb. of dry polymer.

There are three recovery lines, as described above, to handle latex from three of the reactor groups. The fourth speciality reactor group is served by batch strippers which are simply blow-downs equipped with necessary condensers, compressors and other facilities so that degassing of butadiene and stripping of styrene can take place with the latex remaining in the same vessel.

Latex from the blend tanks is pumped to the finishing lines in which the rubber is coagulated, filtered, washed, dried, baled and packaged. The first step in the finishing operation is the addition of an antioxidant to the latex, the function of the antioxidant being to protect the raw polymer and finished rubber articles from oxidative degradation. Different antioxidants are used depending on the end-use of the polymer. An antioxidant which will not discolour the rubber is required when the finished articles will be light-coloured. After incorporating the antioxidant, sodium chloride brine and dilute sulphuric acid are added to coagulate the latex. The sulphuric acid converts the soap to fatty or resin acid and thus breaks the emulsion and coagulates the polymer. The fatty or resin acid remains with the polymer and becomes a part of the finished product. The brine controls the size of polymer-crumb produced. The coagulated polymer is separated from the aqueous phase (serum) and washed on a continuous rotary filter, conveyed to a Jeffrey hammer mill and to a three-pass tunnel drier with perforated aprons. Air is circulated through the aprons and flows countercurrently to the rubber in the drier, heat being provided with steam coils above the aprons. Steam usage is approximately 0.7 lb./lb. of dry polymer. From the driers the rubber passes to hydraulic balers and is formed into 80-lb. bales, which are dusted with talc to prevent their sticking to the bags. The bagged bales are stacked in a warehouse ready for shipment to rubber factories.

The company produces all of the steam, electric power and cooling water used for processing in the plant and supplies some of each to nearby refineries and chemical plants. The steam and power plant contains six boilers with a total capacity of 1,940,000 lb. per hour of superheated steam at 420 p.s.i.g. and 625°F. The principal fuel is pulverised coal, but provision is made to burn fuel oil in an emergency and fuel gas when there is a surplus. About 500,000 tons a year of coal from the eastern United States is brought by train to ports on Lake Erie and is then shipped to Sarnia. Electricity is produced by three turbogenerators using 420 p.s.i.g. steam and exhausting 165 p.s.i.g. steam for use in the process units. About 15,000 kW of power, produced efficiently in this way, are used to drive electric motors in the process units. Cooling water is drawn from the St. Clair River at a rate of 100,000 Imperial gallons a minute.

Energy Requirements for Processing

As in the synthetic rubber industry generally, the energy requirements at the plant are high. The energy is supplied partly by the coal and oil already mentioned, and partly by fuel gas burned in process furnaces or otherwise used as fuel. Over 15,000 horse-power of gas-fuelled internal-combustion engines are used to drive compressors in the process units. Total energy consumption in 1955 was the equivalent of 700,000 short tons of coal. The feed preparation units use a substantial part of this energy. In the light ends recovery unit the energy is used mainly for the pyrolysis reaction to make ethylene from ethane and for compression and refrigeration used in the separation process. The isobutylene extraction unit takes energy for mixing and cooling in the reactor section, for regeneration of isobutylene from the acid extract, and for recovery and reconcentration of the sulphuric acid. In the butylene concentration unit most of the energy is used in the heating and cooling of the fractionation steps.

Much of the energy for the butyl rubber unit is taken for refrigeration. Another large portion is required for compression and separation of the unreacted feed and methyl chloride diluent. Much energy is also used to dry and mill the synthetic rubber crumbs to produce the finished product. Taking into account the energy requirements for the butyl rubber unit, and the isobutylene share of the isobutylene and light ends recovery units, it is estimated that some 40,000 Btu of energy are used at the plant for every pound of butyl rubber produced.

The butadiene units are the largest individual energy consumers at Sarnia. Most of this energy is used in providing the energy and temperature requirements of the butylene dehydrogenation reaction. Part of the heat in the reactor effluent, however, is recovered in waste-heat boilers and in heaters for the steam plant boiler fed-water. Much energy is also required to compress and separate the dilute butadiene product. In the butadiene extraction unit, energy is used to provide refrigeration for the solvent extraction section and to recover the solvent and pure butadiene product.

In the styrene units, as in the butadiene units, most of the energy is used in dehydrogenation reaction. In the ethylbenzene unit, the energy released during alkylation is at too low a temperature to be recovered. The ethylbenzene recovery section and the styrene recovery section use substantial amounts of energy for distillation. The copolymer unit uses much energy in removing heat from the polymerisation reactors on cold recipes. Compression of unreacted butadiene and drying of rubber are other large energy consumers. The copolymer unit is a heavy consumer of electrical energy for motors driving polymerisation-reactor agitators, Jeffrey hammer mills and the numerous pumps and conveyors which move various materials through the process. By calculating the energy requirements for styrene and butadiene production, the energy consumption per pound of butadiene-styrene rubber is estimated at over 60,000 Btu.

ESTIMATION OF H.E.T.P. VALUES FOR BINARY DISTILLATION COLUMNS

For many binary systems, a maximum fractionating efficiency is obtained near the packing loading velocity. In this article a correlation is presented for estimating H.E.T.P. values for Raschig rings at this velocity

by W. H. GRANVILLE, Ph.D.

A PACKED distillation column differs from a bubble-cap column in as much as there is no one definite plate upon which the vapour and liquid streams approach equilibrium before passing to the succeeding plate. Instead, the interchange between vapour and liquid takes place gradually as they flow past each other in opposite directions. A definite length of packing is therefore required to produce the same fractionating effect as one theoretical plate as measured on the McCabe-Thiele[1] diagram. Peters[2] has defined this length as the "height equivalent to a theoretical plate", and is denoted by the abbreviation H.E.T.P. The average H.E.T.P. of a column is therefore given by the equation:

$$H.E.T.P. = \frac{Height\ of\ column}{Number\ of\ theoretical\ plates} \quad \ldots . (1)$$

This method of analysis has been criticised because the calculation of the number of theoretical plates on the McCabe-Thiele diagram is a stepwise procedure, whereas the process in a packed column is continuous. Because of this fundamental difference, Chilton and Colburn[3] have proposed that it is better to design a column in terms of the "height of a transfer unit" based on an overall gas-phase driving force, denoted by the abbreviation $(H.T.U.)_{OG}$. The $(H.T.U.)_{OG}$ method is based on a differential treatment of the column conditions and is defined by the following equations.

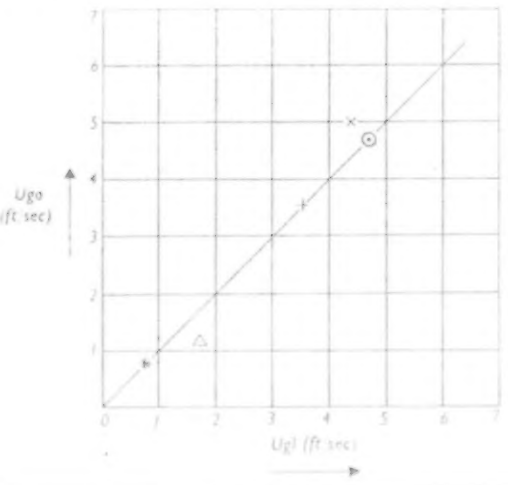
$$(H.T.U.)_{OG} = \frac{Height\ of\ Column}{Number\ of\ Transfer\ units,\ (N.T.U.)_{OG}} \quad \ldots . (2)$$

$$(N.T.U.)_{OG} = \int_{y_2}^{y_1} \frac{dy}{y - y^*} \quad \ldots . (3)$$

In Equation (3), y denotes the vapour composition and y^* the vapour which is in equilibrium with the liquid at the point in the column for which y is taken.

When the slope of the operating line is equal to that of the equilibrium curve, then the number of theoretical plates is equal to the number of transfer units, or H.E.T.P. $= (H.T.U.)_{OG} = (H.T.U.)_{OL}$. Garner, Ellis and Fosbury[4] have shown that for dilute solutions in liquid-liquid extraction the reciprocal of the H.E.T.S. (height equivalent to a theoretical stage) is equal to the log mean value of the reciprocals of the overall film H.T.U. values. Ellis[5] has extended this theory to those distillation systems in which the equilibrium curve may be taken as a straight line, when the H.E.T.P. is equal to the log mean value of the reciprocals of the $(H.T.U.)_{OG}$ and $(H.T.U.)_{OL}$ values, and has illustrated the validity of the theory by testing some of the data of Furnas and Taylor.[6]

Although the $(H.T.U.)_{OG}$ method is generally regarded as being more rigorous, since it is based on a differential treatment of column conditions, the H.E.T.P. method is more readily adopted. Since both units measure the efficiency of the packing, it is reasonable to assume that



KEY			
Symbol	Packing	Packing Dia	Tower Dia
×	Berl Saddles	25 mm	400 mm
○	Raschig Rings	35 mm	400 mm
+	" "	25 mm	400 mm
△	" "	8 mm	400 mm
*	Fenske Helices	5/16 in	2 in

Fig. 1. Comparison of loading velocities, Ugl, and optimum velocities, Ugo.

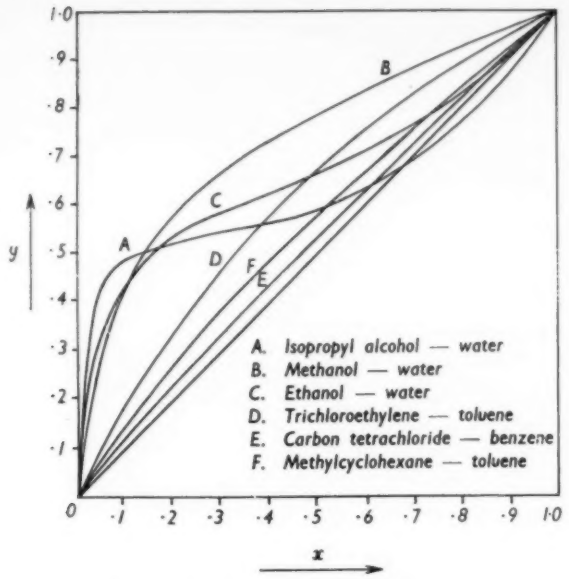


Fig. 2. Vapour-liquid equilibria data.

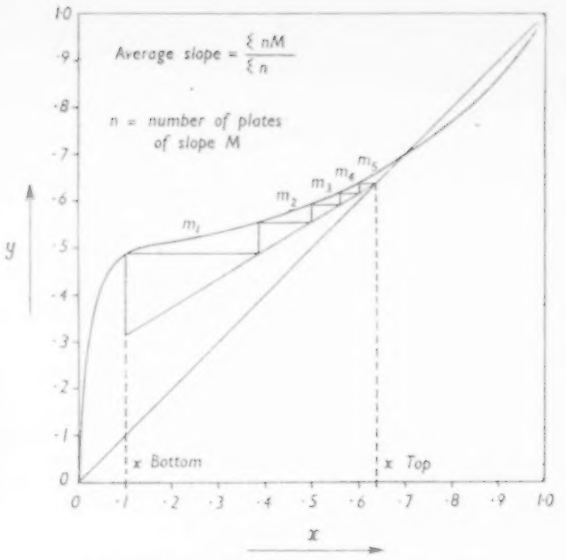


Fig. 3. Determination of average slope, Ma.

both H.E.T.P. and $(H.T.U.)_{OG}$ values will be affected by the same variables, though not to the same extent.

Previous Work

Peters[2] determined the H.E.T.P. of ring packings from $\frac{1}{16}$ in. to 1 in. in diameter and showed that the H.E.T.P. was proportional to the packing diameters. Carswell[7] explained these data by assuming that the efficiency with which equilibrium was reached in any section of the column was directly proportional to the surface over which the reflux was distributed, and indirectly proportional to the volume of the space through which the vapour ascended. When the height of the cylinder was equal to the diameter, and when the packing had thin walls, Carswell showed that the expression reduced to the fact that the H.E.T.P. was proportional to the packing diameter. Substituting the data of Peters, Carswell obtained Equation (4):

$$H.E.T.P.\ (in.) = 24 \times (packing\ diameter,\ in.) \quad \ldots . (4)$$

Peters'[2] data also showed that the H.E.T.P. varied with the nature of the liquids and stated that the H.E.T.P. was greater for liquids of higher molecular weight. Carswell attributed these variations to volume effects and derived the following equation:

$$H.E.T.P. = \frac{k\ M'\ \rho}{T} \quad \ldots . (5)$$

where k = proportionality constant; M' = average molecular weight; T = absolute temperature of distillation, and ρ = liquid density at the distillation temperature.

From Peters' data, the constant varied from 78 to 96, except for the systems nitric acid-water and acetic acid-water, when the values were 200 and 316 respectively. Carswell attributed these differences to the possibility of the vapours being associated.

The main objection to this approach is that it is now known that the effective surface area and free volume are not constant for a particular packing as Carswell assumed, but vary with the vapour and liquid rates.

Fenske, Tongberg and Quiggle[8] realised the complexity of packed distillation columns, and from their results with Fenske helices showed that the H.E.T.P. increased with an increase in packed height, the effect being more pronounced in smaller columns. The H.E.T.P. also increased with the packing diameter and the velocity effect varied with different packings and packing diameter. Contrary to Peters, these investigators showed that different hydrocarbons gave approximately the same H.E.T.P. Fenske, Lawroski and Tongberg[9] did some further work on Fenske helices and other packings, and found that the results differed according to the technique used. The best efficiency was obtained if the packing was wetted by flooding the column just prior to use, and they suggested that this was due to surface tension effects that caused the condensate to coalesce on dry, but to spread uniformly on wet packs.

The effect of boil-up rate under total reflux conditions has been shown by Kirschbaum,[10] who determined the efficiencies of Raschig rings and Berl saddles of various sizes up to $1\frac{1}{2}$ in. in diameter. All the curves had the same characteristic shape, but the variations due to boil-up rates were much more critical with the smaller packings. As the boil-up rate was first increased, the efficiency decreased. Further increase in the boil-up rate then caused an increase in efficiency. Finally, at still higher boil-up rates, the efficiency decreased rapidly. Kirschbaum explained that the initial decrease in efficiency was due to a shorter time of contact, and the next increase in efficiency was due to a better interchange at the higher velocities and an increase in phase-contact surface. The final decrease in efficiency he attributed to channelling effects. This work shows that for Raschig rings, Berl saddles, and possibly other packings, there exists an optimum boil-up rate which gives a minimum H.E.T.P.

Changes in packing efficiencies with increasing boil-up rates have also been reported by Stuke,[11] Pratt,[12] Duncan, Koffolt and Withrow,[13] Murch,[14] Fisher and Bowen,[15] and Garner, Ellis and Granville.[16] Murch has reported curves similar to those of Kirschbaum for ring, McMahon and Stedman packings, whilst Fisher and Bowen have stated that for $\frac{1}{8}$-in. stainless-steel McMahon packings this optimum velocity occurred in the region of the loading point. This importance of the loading point has since been stressed by Garner, Ellis and Granville, who obtained similar results on $\frac{1}{4}$-in. Raschig rings.

Kirschbaum compared the minimum H.E.T.P. of his various packings at the optimum velocity and showed that the H.E.T.P. increased as the packing diameter increased.

Murch[14] has presented the following equation for ring, McMahon and Stedman packings:

$$H.E.T.P. = k_1\, G^{k_2}\, D^{k_3}\, h^{l}\, \mu\alpha/\rho \qquad \ldots.(6)$$

where k_1, k_2 and k_3 are constants dependent on the size and shape of packing; G = mass velocity; D = tower diameter; h = packed height; μ = viscosity; α = relative volatility; and ρ = liquid density. Such an equation can only be used over very limited changes in mass velocity, because the curves of Murch show that the value of k_2 changes with boil-up rate. However, it is interesting to note the effect of packed height, which is the same kind of effect as that shown by Fenske, Tonberg and Quiggle.[8] What is even more interesting is the fact that the exponent 0.33 compares very favourably with the exponent −0.35, which may be obtained from the work of Mayo, Hunter and Nash[17] for the effect of wetting with packed height. For example, from this work it may be shown that the wetted area is proportional to $h^{-0.35}$, and if the H.E.T.P. varies inversely with the wetted area, then the H.E.T.P. would be expected to be proportional to $h^{0.35}$, which is similar to Equation (6).

Robinson and Gilliland[18] have proposed the following equation as a rough guide for predicting the H.E.T.P. of packed columns:

$$H.E.T.P.\ (ft) = \frac{D}{Mg}\left[12\ G^{0.2} + \frac{G}{H\,P\,D_v\left(\frac{L}{\mu}\right)^{0.75}\left(\frac{\mu}{\rho\ D_v}\right)^{0.5}}\right] \qquad \ldots.(7)$$

where D = tower diameter, ft; Mg = average molecular weight of vapour phase; G = vapour mass velocity, lb/hr ft²; H = Henry's Law constant, lb mols./cu. ft. atm.; P = absolute pressure, atm.; L = liquid rate, lb/hr ft²; D_v = diffusivity of solute gas in liquid, sq. cm./sec.; μ = liquid viscosity, poises; and ρ = liquid density. gm./cc.

Although this equation does not directly include the packing diameter, one of the conditions is that the packing diameter must not be less than one-tenth of the tower diameter. Since this is the ratio usually used in practice, it follows that Equation (7) is really a function of packing diameter. However, under total reflux conditions, when $L = G$, Equation (7) shows that the H.E.T.P. for a given system and column is approximately proportional to $G^{0.2}$, which is contrary to the results of Kirschbaum,[10] except over very limited ranges.

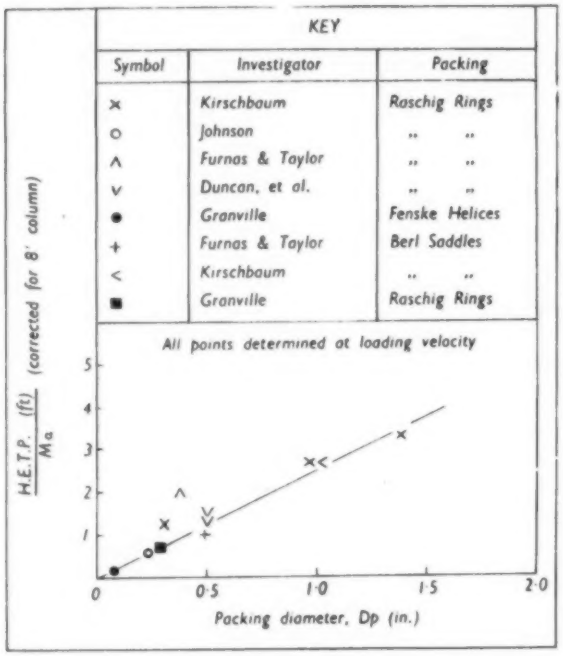


Fig. 4. Effect of packing diameter on H.E.T.P. at the loading velocity.

In attempting to separate the resistance of gas and liquid films, Colburn[19] has shown that for any point on the equilibrium curve,

$$(H.T.U.)_{OG} = H.T.U._G + H.T.U._L\ M\ Gm/Lm \qquad \ldots.(8)$$

where $(H.T.U.)_{OG}$ = overall gas film, H.T.U.; $H.T.U._G$ = individual gas film, H.T.U.; $H.T.U._L$ = individual liquid film, H.T.U.; Gm/Lm = molal vapour rate/molal liquid rate; and M = slope of equilibrium curve at that point. This equation has been used as a basis for $(H.T.U.)_{OG}$ correlations, the main difficulty, however, being to select an average value of M.

Furnas and Taylor[6] have proposed the following equation for Raschig rings and Berl saddles, assuming that $H.T.U._G$ is approximately zero:

$$(H.T.U.)_{OG}\ (\text{ft.}) = \frac{145\ G}{\frac{1}{M}\left(\frac{L}{\mu'}\right)^{1.21}} \qquad \ldots.(9)$$

where G = gas mass velocity, lb/hr ft²; L = liquid rate, lb/hr ft²; μ' = liquid viscosity, lb/hr ft; and M is determined graphically from Equation (8), assuming $H.T.U._G = 0$.

Another method of correlating $(H.T.U.)_{OG}$ data has been to plot this value against the integrated mean value of M with the molal vapour to liquid rate ratio as a parameter, neglecting the effect of the boil-up rate. The data of Duncan, Koffolt and Withrow[13] on ½-in. carbon rings and that of Minard, Koffolt and Withrow[20] on fibrous glass both showed an increase in $(H.T.U.)_{OG}$ with each of the variables M and Gm/Lm. Deed, Schutz and Drew[21] obtained a correlation of data on ½-in. Raschig rings by plotting $(H.T.U.)_{OG}$ against the product $M.Gm/Lm$, using the integrated mean value of M. They neglected the effects of boil-up rate, which might have reduced some of the scattering of the data obtained. Herman and Kaiser[22] have mentioned the importance of boil-up rate on $(H.T.U.)_{OG}$ data obtained on fibrous glass and also showed that the H.E.T.P. and $(H.T.U.)_{OG}$ data were affected to the same extent by variations in M and Gm/Lm.

Ellis[23] has included the principles of the $(H.T.U.)_{OG}$ correlations to derive an equation for the prediction of H.E.T.P. data for 1-in. to 2-in. Raschig rings in the form:

$$H.E.T.P.\ (in.) = 18\ D_p + 12\ M\ (G/L - 1) \qquad \ldots.(10)$$

This equation is for a packed height of 10 ft, and Dp = packing diameter, in.; G = vapour rate lb/hr ft²; L = liquid rate lb/hr ft²; and M is the slope of the equilibrium curve for the average vapour composition entering and leaving the column. Although this equation neglects the effect of boil-up rate, it does include a height factor, because Ellis has stated that, when the packed height is not 10 ft, then the change in H.E.T.P. must be allowed for by assuming that it is proportional to the square root of the packed height.

Since the $M.Gm/Lm$ factor has an important effect on the $(H.T.U.)_{OG}$ and H.E.T.P. data of these systems, it follows from Equation (8) that the liquid film resistance, $H.T.U._L$, is substantial. Indeed, it has been proposed by Furnas and Taylor that distillation systems are liquid film controlling.

It may be concluded from the above survey that the efficiency of a packed distillation column depends on the type and size of packing, the packed height, the relative slopes of the equilibrium curve and operating line, the boil-up rate, the degree of wetting, and, possibly, the physical properties of the mixture being separated.

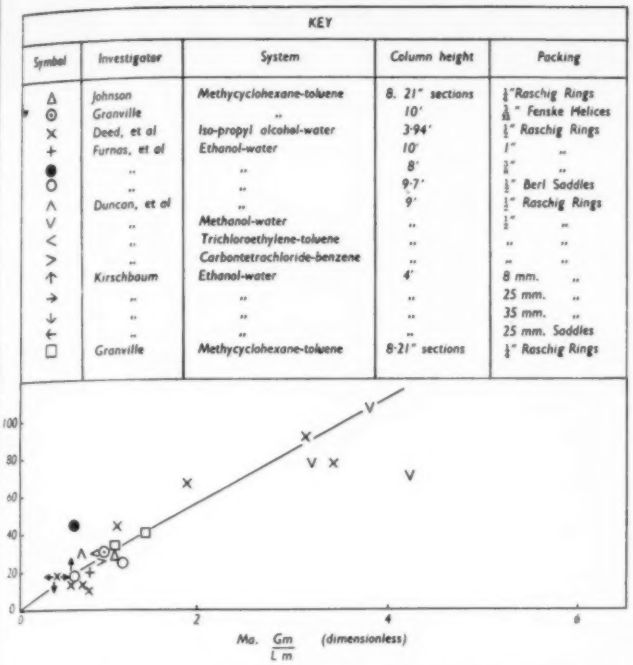

KEY
Symbol | Investigator | System | Column height | Packing
Δ Johnson | Methycyclohexane-toluene | 8. 21" sections | ⅛"Raschig Rings
◎ Granville | " | 10' | 3/32" Fenske Helices
× Deed, et al | Iso-propyl alcohol-water | 3·94' | ¼" Raschig Rings
+ Furnas, et al | Ethanol-water | 10' | 1" "
● " | " | 8' | ¾" "
○ " | " | 9·7' | ½" Berl Saddles
∧ Duncan, et al | " | 9' | ½" Raschig Rings
∨ " | Methanol-water | " | ½" "
< " | Trichloroethylene-toluene | " | " "
> " | Carbontetrachloride-benzene | " | " "
↑ Kirschbaum | Ethanol-water | 4' | 8 mm. "
→ " | " | " | 25 mm. "
↓ " | " | " | 35 mm. "
← " | " | " | 25 mm. Saddles
□ Granville | Methycyclohexane-toluene | 8·21" sections | ¼" Raschig Rings
Carrying for 8" Column
100
80
60
40
20
0
2
4
6
Ma. Gm/Lm (dimensionless)

Fig. 5. Correlation of H.E.T.P. data at the loading velocity.

Significance of the Loading Velocity

Experimental work by the author[24] on ¼-in. Raschig rings and 3/32-in. Fenske helices have shown that the optimum vapour velocity for each packing which corresponded to the maximum fractionating efficiency was actually the loading velocity, as determined from pressure-drop measurements. Since the same result was obtained by Fisher and Bowen[15] for ¼-in. McMahon packing, the loading velocities for the packings used by Kirschbaum[10] were predicted, and the loading velocities are plotted against the optimum velocities for several packings in Fig. 1. This graph shows that the optimum velocity at which a column has a minimum H.E.T.P. is near the loading velocity (see also Table 1).

Correlation for H.E.T.P. Data at the Loading Velocity

All previous methods suggested for correlating H.E.T.P. or $(H.T.U.)_{OG}$ data for packed distillation columns have resulted in equations where the H.E.T.P. or $(H.T.U.)_{OG}$ values are continuous functions of the vapour rate, or in other cases independent of the vapour rate. It is now known that the H.E.T.P. values of such packings as Raschig rings, Berl saddles and Fenske helices are not continuous functions of the vapour rate, but that such functions are very complex, containing maximum and minimum values of H.E.T.P. In attempting to compare the H.E.T.P. data for various packings and systems, it is suggested that it would be better to compare such systems at their loading velocities, since this would avoid comparing the maximum H.E.T.P. of one system with the minimum H.E.T.P. of others, and also such a correlation in itself would not need to include the vapour rate directly, thereby simplifying the resulting correlation.

Data for this new H.E.T.P. correlation have been selected mainly from the work of Deed, Schutz and Drew,[21] Duncan, Koffolt and Withrow,[13] Furnas and Taylor,[6] Kirschbaum,[10] Johnson,[25] and the author.[24] The systems investigated are iso-propyl alcohol-water, methanol-water, ethanol-water, trichloroethylene-toluene, carbon tetrachloride-benzene and methylcyclohexane-toluene, and the shapes of the vapour-liquid equilibrium curves for these systems are shown in Fig. 2. Most of the data are for ¼-in. Raschig rings, but some data are also given for other size rings and packings as shown in Figs. 4 and 5.

It has been shown by Murch[14] that the H.E.T.P. of a packed column is proportional to the cube root of the packed height and it was explained in the literature survey that this was in agreement with the results of Mayo, Hunter and Nash[17] on the wetting of packings. Since the data used in the present work were obtained on columns varying in height from 2 ft to 10 ft, the H.E.T.P. data have been corrected according to the cube root law to those values which would have been obtained on an 8-ft column.

The starting point for the correlation is Equation (8), which has been derived theoretically. The work of Furnas and Taylor[6] has indicated that distillation systems are liquid film controlling and therefore $H.T.U._G$ tends to zero. Since both $(H.T.U.)_{OG}$ and H.E.T.P. values are measures of the performance of a colmn, it follows that the H.E.T.P. must also be dependent on $M.Gm/Lm$ and $H.T.U._L$. The $H.T.U._L$ value cannot be calculated theoretically, since the results of previous workers have shown that it varies with the hydraulic conditions of the packing size, and possibly the physical properties of the system. However, it has been shown by Garner, Ellis and Granville[16] that for a given system in a given column operating at the loading point, that:

$$H.E.T.P. = Constant \times Ma \frac{Gm}{Lm} \qquad \ldots . (11)$$

where Ma is the average slope of equilibrium curve over the section where Gm/Lm is taken, Gm/Lm being the reciprocal of the slope of the operating line. The method of determining the average slope is as follows:

The total height, h, of a section of a column is equal to the sum of the H.E.T.P. values for each theoretical plate.

$$\begin{aligned} h &= H.E.T.P._1 + H.E.T.P._2 + H.E.T.P._3 \\ &= \Sigma\, H.E.T.P._1 \\ &= \Sigma \left(constant\ M_1 \left(\frac{Gm}{Lm} \right)_1 \right) \\ &= constant\ \Sigma\ M_1 \left(\frac{Gm}{Lm} \right)_1 \end{aligned}$$

For any section of the column, Gm/Lm is constant, and so for any section

$$h = constant \frac{Gm}{Lm} \Sigma\, M_1.$$

The average H.E.T.P. for that section is then given by

$$H.E.T.P. = constant \frac{Gm}{Lm} \frac{\Sigma\, M_1}{number\ of\ theoretical\ plates}$$

which is identical to Equation (11) when:

$$Ma = \frac{\Sigma\, n\, M}{\Sigma\, n} \qquad \ldots . (12)$$

In Equation (12), n is the number or fraction of plates corresponding to a slope M of the equilibrium curve.

This method of determining the average value of M is considered better than taking the integrated mean value as may be demonstrated in Fig. 3. The bottom plate covers as much of the equilibrium curve as do the remaining four plates. Thus it would be expected that the latter half of the equilibrium curve would be much more important than the half corresponding to the bottom plate. In other words, it is necessary to use a weighted average value of M, which is what is being done by determining Ma from Equation (12).

If the effect of the physical properties of various systems are neglected, and all systems and packings operated at the loading point, then under total reflux conditions when Gm/Lm is unity, it follows from Equation (11) that H.E.T.P./Ma is a function of the packing diameter. (It may be argued that the column diameter should be considered, but for the data selected the column diameters were approximately eight to twelve times the packing diameter, and so this column factor is being included.) The effect of this packing diameter is shown in Fig. 4, from which it follows that under total reflux conditions at the loading point, and for a column section of 8 ft, that:

$$H.E.T.P.\ (in.) = 28\ Ma\ Dp\ (in.) \qquad \ldots . (13)$$

Comparing Equation (13) with Equation (11), it follows that the overall correlation of H.E.T.P. data at the loading point should be:

$$\frac{H.E.T.P.}{Dp} = constant\ Ma\ \frac{Gm}{Lm} \qquad \ldots . (14)$$

Fig. 5 shows a plot of Equation (14) at the loading velocities for a wide range of packings and systems. The data are also given in Table II. From Fig. 5 the following dimensionless equation is obtained:

$$\frac{H.E.T.P.}{Dp} = 28\ Ma\ \frac{Gm}{Lm} \qquad \ldots . (15)$$

Equation (15) agrees with Equation (13) because, when Gm/Lm is put equal to unity for total reflux conditions, then both equations become identical.

TABLE I

Optimum and Loading Velocities

Packing	Packing Diameter	Optimum Velocity	Loading Velocity
Porcelain Berl Saddles[10]	22 mm.	5.1	4.4
Porcelain Raschig Rings[10]	35 mm.	4.7	4.6
,, ,, ,,	25 mm.	3.6	3.6
,, ,, ,,	8 mm.	1.1	1.8
McMahon[15]	$\frac{1}{2}$ in.	1.8	1.8
Fenske Helices[24]	$\frac{3}{32}$ in.	0.9	0.9
Raschig Rings[24]	$\frac{1}{4}$ in.	0.6	0.6

TABLE II

Data for Correlation of H.E.T.P. at the Loading Velocity

Packing	Dp	Column Height (ft.)	$\frac{Gm}{Lm}$	Ma	$\frac{Ma \cdot Gm}{Lm}$	H.E.T.P. for 8-ft. column (in.)	H.E.T.P. (in.) / Dp (in.)
Raschig rings	$\frac{1}{8}$ in.	3.94	1.7	0.48	0.82	5.9	11.8
(stoneware)	$\frac{1}{8}$ in.	3.94	1.72	0.50	0.86	4.2	8.4
,,	$\frac{1}{4}$ in.	3.94	1.1	0.50	0.55	8.8	17.5
,,	$\frac{1}{4}$ in.	3.94	1.4	0.50	0.70	5.8	11.5
,,	$\frac{1}{2}$ in.	3.94	1.79	0.67	1.20	22.8	45.6
,,	$\frac{1}{2}$ in.	3.94	2.32	0.83	1.92	33.4	66.8
,,	$\frac{1}{2}$ in.	3.94	2.13	1.50	3.2	45.6	91.2
(carbon)	$\frac{1}{2}$ in.	9.0	2.4	1.60	3.4	38.0	76.0
,,	$\frac{1}{2}$ in.	9.0	1.3	0.57	0.74	16.1	32.2
,,	$\frac{1}{2}$ in.	9.0	1.6	2.7	4.3	35.0	70.0
,,	$\frac{1}{2}$ in.	9.0	1.6	2.3	3.8	52.5	105.0
,,	$\frac{1}{2}$ in.	9.0	2.0	1.6	3.2	37.2	74.4
,,	$\frac{1}{2}$ in.	9.0	1.0	0.91	0.9	14.9	29.8
,,	$\frac{1}{2}$ in.	9.0	1.0	1.0	1.0	13.1	26.2
(stoneware)	1 in.	10.0	1.0	0.95	0.95	18.0	18.0
,,	$\frac{3}{4}$ in.	8.5	1.0	0.70	0.70	18.0	48.0
,,	$\frac{3}{4}$ in.	8.5	1.23	0.72	0.90	25.2	65.0
Berl saddles (stoneware)	$\frac{1}{2}$ in.	9.7	2.1	0.53	1.1	12.8	25.6
,,	$\frac{1}{2}$ in.	9.7	1.0	0.72	0.72	8.2	16.4
Raschig rings (porcelain)	8 mm.	3.92	1.0	0.63	0.63	9.1	28.6
,,	25 mm.	3.92	1.0	0.53	0.53	16.8	17.0
,,	35 mm.	3.92	1.0	0.50	0.50	14.2	14.0
Berl saddles (porcelain)	25 mm.	3.92	1.0	0.53	0.53	16.8	17.0

Conclusions

(1) A packed distillation column has a minimum value of H.E.T.P./Ma Gm/Lm in the region of the loading velocity.

(2) When the efficiencies of various packings are compared at the loading point, then the H.E.T.P./Ma Gm/Lm values are proportional to the nominal size of the packing. This is in agreement with the work of Carswell[7] who explained this result to a surface area effect, but he neglected the effect of boil-up rate on the effective surface area as opposed to the calculated surface area. Since a condition approaching maximum effective wetting for binary distillation systems is obtained in the region of the loading point, it follows that the packing diameter effect originally proposed by Carswell should hold more soundly.

(3) Murch's[14] statement that the H.E.T.P. is proportional to the cube root of the packed height has been used to correct data for the final correlation. The reasonable correlation shown in Fig. 5 confirms Murch's statement.

(4) The importance of the Ma Gm/Lm factor has been demonstrated and Table II shows how significant this factor can be.

(5) It would be expected that the physical properties of the system would have an effect on the H.E.T.P. obtained. Although no such variables appear in the final equation, it should be pointed out that the Ma value is a function of the change of relative volatility of the system with composition, and that, in correlating at the loading velocity, one has to incorporate the physical properties of the system to select this point.

(6) Equation (15) has been obtained mainly on data for Raschig rings, but the data shown in Fig. 5 indicate that it may also hold for Berl saddles.

Nomenclature for New Correlation

Dp = nominal packing diameter;

M = slope of vapour liquid equilibrium curve;

Ma = average slope of vapour liquid equilibrium curve which equals $\frac{\Sigma n M}{\Sigma n}$;

n = number of plates corresponding to a slope M on the vapour liquid equilibrium curve; and

Gm/Lm = molal vapour rate divided by the molal liquid rate which is the reciprocal of the slope of the operating line.

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ELECTRO-PRECIPITATORS IN THE CHEMICAL INDUSTRY

— THEIR APPLICATIONS, COST AND OPERATION

by Dr. R. F. HEINRICH and J. R. ANDERSON, A.M.I.E.E.

IN general, electro-precipitation can be effectively applied to any process where entrained dust, smoke, fume or mist in a gaseous carrier needs to be recovered; either for its intrinsic value, to prevent clogging or contamination later in the process stream, or purely to prevent a nuisance.

It was shown in a previous article* how any particulate matter can be given a charge and electrically precipitated out of the carrying medium by the high field strength set up between the discharge electrode and the receiving electrode. It was also shown that a formula has been derived to indicate the theoretical efficiency expected for a given set of conditions and how the many variables affected the migration velocity introduced into the formula. The size of particle, its electrical resistivity, the field strength and the gas velocity all had a considerable influence on the process.

Electro-precipitators have for many years been successfuliy applied to a variety of processes in the chemical industry and precipitators have become, in many instances, an indispensable part of the plant.

Sulphuric Acid Plants

Nowadays, for instance, almost all contact-sulphuric acid plants use electro-precipitators for dust removal from the SO_2-bearing roaster gases at temperatures of 350-500°C and for the precipitation of the arsenic, selenium, etc., which are often contained in the gases. These substances are very unpleasant contact poisons and lead to constant contamination of the sulphuric acid unless removed from the roaster gases. This separation is performed by the so-called hot gas electro-precipitators which operate between 350-500°C, i.e., above the dewpoint of the H_2SO_4 which is present in these gases.

Hot gas precipitators are sometimes fitted with cyclone pre-cleaners, as the dust carry-over varies considerably between Herreshoff, Flash and Turbulent Layer roasters.

Horizontal-flow plate-type precipitators are preferred for this class of work as they give two, three or four zones of series treatment necessary for the desired efficiency. The electro-precipitator casings are of brick and concrete construction or they are constructed in sheet steel with ample lagging to minimise temperature drop. Ease of access is most important so that routine inspection and repairs can be easily carried out.

The almost dust-free hot gases leaving the electro-precipitator are cooled and humidified in wash towers or scrubbers to around 35°C, then passed through cold-gas mist electro-precipitators for fine cleaning for the removal of SO_3 acid mist, arsenic, selenium, etc. Single treatment with a primary precipitator, or series treatment using primary and secondary precipitators, is given to the mist, depending on the arsenic content and the clarity and purity of acid required for its end use.

With good design, hot gas precipitators of very high efficiencies are possible, so much so that it is very difficult to detect any solids in the water effluent from the wash tower or scrubber. With mist electro-precipitators, efficiencies of 99.99% are common on installations producing arsenic-free acid.

Tail-gas mist electro-precipitators are installed to clean-up the ultimate exhaust gas from some sulphuric acid plants. The mist concentration is usually in the range of two to six grains per cu. ft at the operating gas temperature around 35°C with most of the particles below three microns. Mist precipitators also offer a satisfactory answer to the problem of tail-gas clean-up from magnesia kilns. The electro-precipitators follow the scrubbers, the latter being adequate for the removal of the coarser dust passing over from the kiln.

Cement-Sulphuric Acid Plants

In England the anhydrite process consists fundamentally in heating an accurately proportioned mixture of calcium sulphate with materials containing carbon, silica, alumina and ferric oxide, thus producing cement clinker and gases containing sulphur dioxide. The latter is then converted into sulphuric acid by the contact process. The SO_2-bearing gases, together with entrained dust at about 350°C, are passed through a large cyclone where the heavier fractions are separated out and returned to the process. The gas is scrubbed and cooled to 30-35°C with water in a packed tower and then, still containing small quantities of dust, SO_3, H_2SO_4 and water in the form of mist, it is treated in two groups of wet electro-precipitators in series, in which practically all mist and solid particles are removed. The cleaned gas, containing about 6% SO_2 by volume, is oxidised to SO_3 and processed into 96% sulphuric acid. Traces of unconverted SO_2 in the gas leaving the absorber towers are removed by water scrubbers and the tail gas is finally cleaned in wet precipitators before discharging to atmosphere.

Irrigated precipitators have also been successfully applied to the collection of selenium fume during the

* "Electro-precipitation—A method for the recovery of process fumes and dust", *British Chemical Engineering*, 1956, **1**, 418.

preparation of the metal. They are also used for treating the calciner gases from titanium oxide slurry-drying kilns. The precipitators are installed after a scrubber or wash tower and demand several special features to cope with the conditions of operation. However, high efficiencies based on SO_3 recovery are obtainable giving SO_3 emissions from the stack gases under 1% of the statutory limit of 4.0 gr/ft^3.

Phosphoric Acid and Phosphorus Production

Two applications of electro-precipitators are demanded in the production of elemental phosphorus in electric furnaces. First, the cleaning of the furnace gases and, secondly, the collection of the fume given off during the tapping and slagging-out operations. This cleaning of the furnace gases of their entrained dust contaminants whilst permitting the phosphorus vapours to pass on to the condensers was one of the most difficult tasks presented to precipitator manufacturers and took several years of experimental work before a solution was found.

For example, the precipitator chamber must be maintained above the condensation temperature of the phosphorus vapours which is between 275° and 325°C, depending on the concentration of the gases. If this condition is not met, the phosphorus condenses in the precipitator and a hard, crusty dust mixture forms which can only be removed by scraping-down or washing-off with hot water jets. Such cleaning has to be done with great care, since the dust begins to burn the moment it comes in contact with air.

The second application deals with the removal of the extremely fine furnace-room fume and this, again, provided a difficult problem for the precipitator designer. The problem here was that the variable fume concentration from slagging-out, tapping periods and other causes of fume emission must be dealt with and the gases cleaned before emitting to atmosphere. Mist electro-precipitators are also successfully employed in the production of phosphoric acid.

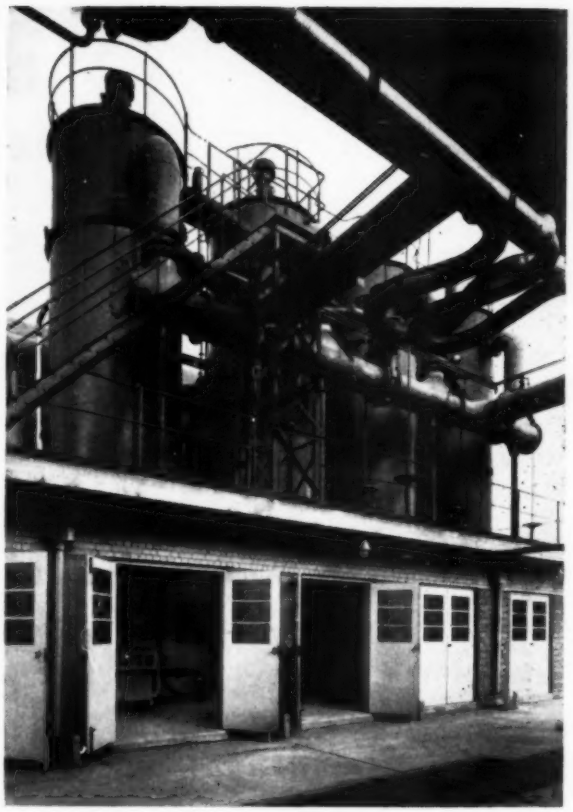
Barium Oxide Production

The production of barium compounds for use as a grease additive by reducing barytes in electric furnaces gives rise to large quantities of barium oxide dust which, with a particle size of one micron diameter, cannot satisfactorily be separated in wet washers or mechanical cleaners.

Irrigated precipitators have been successfully applied to this process in America. The gases are cooled down and humidified to 50°C before passing on to the wet precipitator where the fine dust is recovered from settling tanks. The electro-precipitators not only prevent the barium oxide fume from being a nuisance in the plant surroundings, but pay for themselves in a matter of a few years by the recovery of the valuable barium oxide.

Sulphate Cellulose Manufacture

In the production of sulphate cellulose large quantities of black liquor containing sodium sulphate accumulate. To recover the heat value, the black liquor is sprayed into a furnace and burned. The gases are then passed through a waste-heat boiler and then treated in an electro-precipitator to recover the sodium sulphate fume released in the combustion of the liquor for re-use. It is this treatment of the black liquor which mainly makes the sulphate process economical. The electro-precipitators used have been specially developed to meet the requirements of this process and the corrosive properties of the sodium sulphate.



Electro-detarrers for coke-oven gas treatment as installed at one of the National Coal Board's plants.

Other Applications

In large American and Iranian oil refineries, whose lighter oils and high-quality petrols are produced by the suspension cracking process, full-scale electro-precipitators have recently been built. The electro-precipitators serve to recover the valuable catalyst dust from the catalyst regenerator. This dust is then returned to the process. Without the dry recovery of the expensive catalyst, the suspension cracking process would be uneconomical.

Electro-precipitators have also been successfully applied to many other processes, including the following: borax; chalk dust; clay dust; soap dust; sodium carbonate; calcium arsenate; dolomite dust; gypsum; elemental sulphur mist; calcium cyanide dust; phosphate dust; potash dust; magnesite dust; limestone dust; ceramic dusts; and carbon dusts.

In addition to the fumes from pyrites and zinc blende roasters dealt with earlier, electro-precipitators have been used for the recovery of nearly all the fumes arising from metallurgical smelting or refining processes in the precious metals, steel and non-ferrous metal industries, as well as the cement, coal, electricity, gas and food processing industries.

Capital and Working Costs

Due to the many variables affecting precipitator design and materials of construction to suit particular conditions, it is only possible to give an indication of cost, but the following figures may assist when preparing preliminary project estimates.

(1) Dusts easy to precipitate with resistivities up to 10^{10} ohm cm with a size grading of 30% smaller than 10

microns—from 4 to 8 shillings cfm at operating temperature.

(2) Dust not so easy to precipitate with resistivities above above 10^{10} ohm cm or with a size grading of 60% smaller than 10 microns—from 12 to 20 shillings cfm at operating temperature.

(3) Difficult materials with high resistivities with particle sizing of fumes and mists—from 20 to 60 shillings cfm at operating temperature.

The complete precipitator with casing and all electrical equipment erected and commissioned is included in the above figures, but does not include any special dust-disposal equipment, connecting ducting, foundations, fans, gas-outlet stacks or conditioning towers which may be required.

The range of prices assumes a plant of at least 6000 cfm with a recovery efficiency of 93 to 98%. Smaller plants might cost more per cfm and, likewise, larger plants should cost less per cfm. However, plants designed for a lower efficiency may cost less, whilst plants designed for efficiencies of over 98% may cost more than the range quoted.

Working costs vary widely due to the diverse duties of the fields of application. The power consumed may be anything between 10 and 180 kW per 100,000 cfm of gas treated, whilst replacement and maintenance costs may vary from a few pounds to several hundred pounds a year, depending on the size of the plant and such other factors as the type of precipitator, the nature of the material collected and the type of rectifier used. Two interesting articles on this subject have been given by C. J. Stairmand[1] and J. M. Dallavelle.[2]

Finally, it is always safer to approach one of the specialist concerns to submit a quotation if a plant is seriously being considered.

Operation and Maintenance

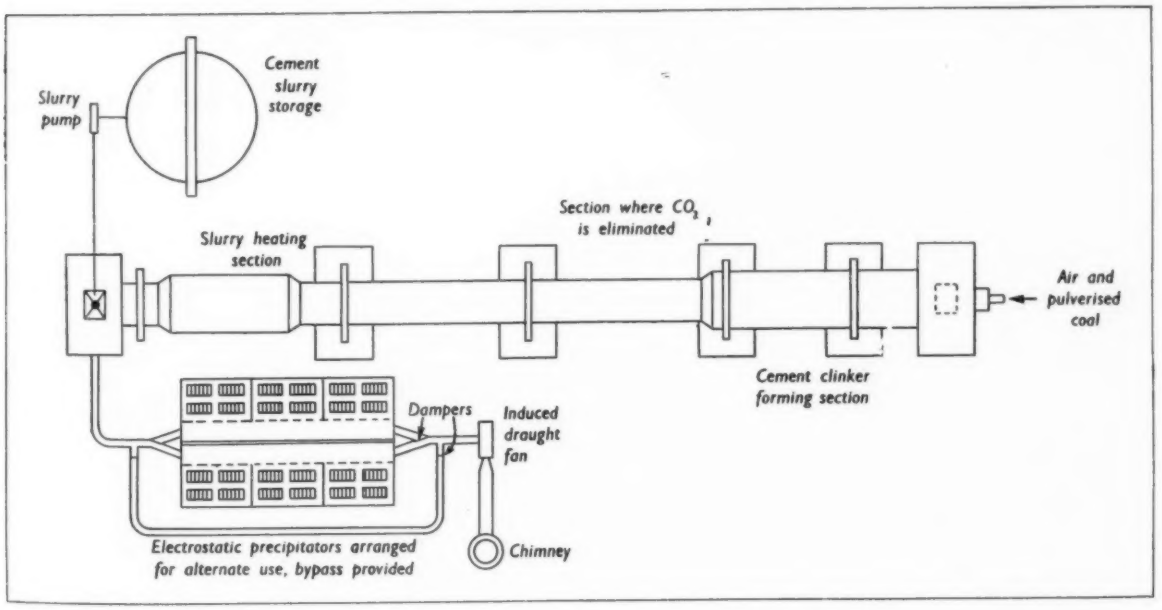
Electro-precipitators, like most other plant, will respond to good treatment. Designers, with some thirty years' experience to back up their choice of components and materials, are in a position to produce plants that will function reliably. However, where particularly arduous conditions are to be encountered, complete freedom from mechanical or electrical faults cannot be expected.

Some installations are the last in a line and tend to be overlooked, especially the plants installed to stop an emission problem. Often the recovered material is a nuisance to dispose of, or has no recovery value. Other installations may be key components in a process line and a shut-down would involve the whole process, with a consequent loss of output and revenue. Too often managements rely on a single precipitator unit to do its vital job of gas cleaning where prudence would demand a stand-by precipitator.

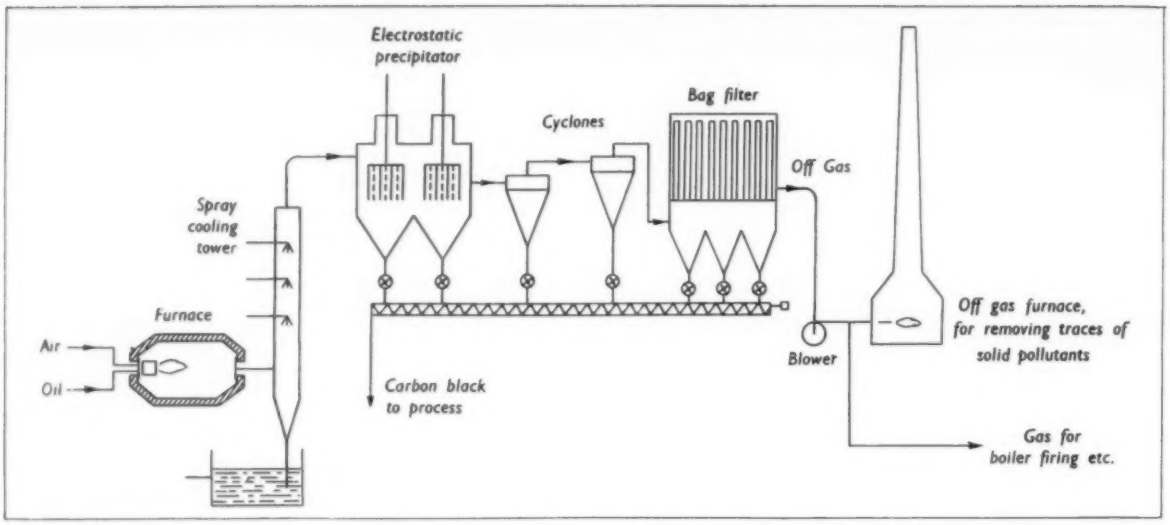
Plants with single key units demand intelligent operation and routine maintenance, otherwise the efficiency of recovery may deteriorate—one essential in all dry precipitators is to keep the discharge and receiving electrodes clean as excessive build-up of dust on the discharge wires will reduce the emission of H.T. current. This build-up, more often than not, prevents the freshly precipitated dust from giving up its charge, thereby causing back ionisation and sparking and erratic operation. Excessive build-up also causes the already precipitated dust to be detached from the electrodes and carried away in the gas stream. It is essential, therefore, to maintain the rapping gear fitted to the discharge and receiving electrodes in good order. One missing hammer would allow build-up to occur, making it necessary to reduce the applied voltage to the whole zone or compartment.

Hopper build-up is another frequent source of trouble which can be eliminated with intelligent operation. It is so easy, but so very wrong, for an operator to open a hopper dust valve and, on finding no dust outflow, to assume the hopper is empty, when, from past experience, he should know that there ought to be so many pounds or hundredweights of dust to come down. Unless the arching over of dust is broken with a poke-rod, the dust continues to build-up until the H.T. discharge wires short-circuit. As a result, the dust begins to cool off and compact and acid formation may make the dust sticky, so that, finally, to clear the hopper may well mean a complete shut-down with consequent loss of production and revenue.

High field strength is also necessary for high efficiency.



Diagrammatic plan of an electrostatic precipitator installation at a cement works.



Electrostatic-precipitators acting as agglomerating devices in a modern carbon-black manufacturing plant.

which means that the applied H.T. voltage at the discharge electrodes must be kept as high as possible. Fluctuating gas or dust conditions may make it necessary to reduce the H.T. voltage, but as soon as stable operating conditions are restored the voltage should again be raised to the optimum setting without which the maximum efficiency cannot be attained. The fitting of automatic voltage control and automatic reclosing devices will ensure that the H.T. units are running at peak settings. However, even when these devices are fitted, the operators should check that the current and voltage readings are up to normal.

Another point that demands vigilance on most chemical plants is air infiltration. This may increase so slowly over a period of time that no clear indication of any obvious increase in air infiltration is given until sulphation has really set in, with a consequent build-up in the precipitator, together with partial blockage of the gas ducting.

Mist electro-precipitators in general give very little trouble, but some slight deterioration in efficiency must be expected if the discharge wires or tubes are allowed to build-up too much with sludge or hard deposits. Regular washing-down is usually sufficient, but in some cases it may be necessary to scrape the deposit from the wires and tubes. Parallel operation or stand-by capacity is very desirable with such plants. Insulators should be periodically checked and a routine laid down for cleaning. Oil seals and insulator housing heaters, if fitted, also require periodical inspection.

After internal repairs or cleaning, a final check over is demanded to see that all discharge wires are firmly fixed and centrally disposed, all rapping mechanism free and, most important of all, that no debris is left inside to cause a short circuit when the plant is recommissioned. Some of this advice may seem obvious, but crow-bars, brooms, brushes and even steel wheelbarrows have been left inside a plant. The presence of less obvious items like welding-rod ends and asbestos string can also cause endless trouble.

The high-tension units supplied nowadays are very reliable, whether they be of the selenium metal oxide or of the rotating mechanical type, and they demand routine maintenance only.

To sum up, there are many thousands of electro-precipitators in operation today operating all over the world under very diverse conditions. With intelligent operation and regular maintenance they can, and do, provide a high efficiency of recovery. However, it must be remembered that electro-precipitators, like any other plant, are limited to the operating conditions for which they have been designed. Such deviations from design conditions as a marked increase in gas through-put or dust or mist concentration, alterations in the particle size analysis, or in temperature and dew-points, might well lead to a falling-off in performance of a particular precipitator. Nonetheless, hundreds of electro-precipitators are today working under conditions very much in excess of the original design conditions, and continue to do good work so long as they are properly maintained and operated.

REFERENCES
[1] Stairmand, C. J. "The Design and Performance of Modern Gas-cleaning Equipment", *Journal Inst. of Fuel*, 1956, **29**, 58.
[2] Dallavelle, J. M. "How to Estimate Dust Collector Costs", *Chem. Eng.*, 1953, **60**, 177.
Costs are also included for other forms of gas-cleaning equipment in the above-mentioned papers.

New Pickling Plant

RECENT DEVELOPMENTS at the Rose Mount Iron Works of Robert Dempster & Sons Ltd., Elland, include a new pickling and painting shop which is now in operation. The new shop has been built on a site within the existing works boundary, the scheme being devised and built to meet an expanding demand for the pickling and painting of steel plates and sections used in gas, chemical and oil plants, and general structures.

The new shop is 200 ft long × 52 ft wide, and 35 ft to the eaves, of rigid-framed portal roof construction, with the lower portion bricked for a height of 9 ft. The three baths are each 35 ft × 5 ft × 9 ft deep, the tops being 3 ft 3 in. above the shop floor level. The shells are of reinforced concrete, lined on the inside with rubber membrane, and clad on the outside and inside with 9 in. thick acid-resisting brickwork set in acid-resisting cement and with bullnose capping.

The whole process is controlled from a laboratory office situated some 10 ft above the shop floor level at the west end of the shop, from which a full view of the whole shop is obtained. The plant is capable of dealing with flat plates or sections to a maximum of 34 ft long × 7 ft wide, whilst curved plates of 35 ft × 7 ft, with a versed sine of up to 4 ft 6 in., can be accommodated at a single dip.

ABSORPTION OF CARBON DIOXIDE IN SOLUTIONS OF DIETHANOLAMINE*

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Comments on Results and Conclusions

Before the theory of the experimental results can be discussed, the data must be compared with other published information on the system. The only useful data yet published, those of Cryder and Maloney, are reported in terms of $K_G a$, the overall mass-transfer coefficient on a volume basis. Absolute comparison is not possible because of the variation of a, the wetted area per unit volume, with the liquor rate in a tower packed with Raschig rings. Such variation was eliminated in the experiments reported here by the use of the disc column. However, a general comparison of the qualitative effects of the principal variables on the absorption coefficient may be undertaken.

Figs. 4 to 8 (*British Chemical Engineering*, 1956, **2**, 18-20), as well as other results given in the tables (p. 80), show the mass-transfer coefficient to be of the same order of magnitude as that reported by Cryder and Maloney.[8] The coefficients show a similar dependence on the liquor rate K_G increasing with increase of the rate. Under certain conditions, however, a maximum is attained, after which the coefficient shows a decrease with increasing liquor rate. The effects of changes in the hydrodynamic conditions of the liquid flowing over the packing discs are evident in Fig. 5, which relates to solutions of high normality (and hence high viscosity). Fig. 6 shows that the overall transfer coefficient decreases as the percentage conversion of the amine solution fed to the absorption column increases (i.e., as the residual free amine in solution decreases), again in agreement with the findings of Cryder and Maloney. It is noticed also that, generally, the rate of absorption (as represented by the overall mass-transfer coefficient) is directly proportional to the residual free amine concentration. Fig. 7 shows the falling off of K_G with increase of the partial pressure of carbon dioxide in the gas stream. The range of gas composition investigated is greater than that studied by Cryder and Maloney, and the results confirm their report of the effect of increasing the partial pressure of the soluble component.

Mass-transfer Coefficient and Normality

Increasing the normality of the solvent at constant liquor rate and constant gas composition has a curious effect on the mass-transfer coefficient as shown in Fig. 8. Cryder and Maloney showed that the mass-transfer coefficient attained a maximum value at an amine normality of between 2 and 3N. Reference to Fig. 8 shows this maximum to be confirmed. It also shows that further increase in the normality of the amine to five, leads, in certain cases, to a further increase in the mass-transfer coefficient. Results shown in the tables (p. 80) indicate that this applies to most cases. This effect was not found by Cryder and Maloney, because the strength of the solutions they used was less than 4N. Dixon,[9] working with monoethanolamine in a centrifugal absorber, found a similar effect. The effect has also been found by Watkins[26] working on the carbon dioxide/caustic potash system. As the normality of the solution increases, its viscosity and absorption capacity are also increased until a point is reached at which the effect of the viscosity begins to counterbalance the rate of absorption. Also shown on Fig. 8 are the K_G values for the absorption of carbon dioxide in water. It is seen that the curves converge, as expected, on this "zero normality" intercept.

Because of the complexity of the reactions between carbon dioxide and diethanolamine, it was realised that any correlation of the results would necessarily involve some simplifying assumptions. Van Krevelen and Hoftijzer[24] obtained an approximate correlation of the data of Cryder and Maloney[8] by using the following equation:

$$Sh = c\, Re^{\frac{1}{2}}\, Sc^{\frac{1}{3}}\, Ha \qquad \ldots.(7)$$

the Hatta group taking the form:

$$Ha = \frac{\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} \cdot \left(\frac{k_{III} q^2}{D}\right)^{\frac{1}{2}}}{tan\, h \left(\frac{\mu}{g\rho^2}\right)^{\frac{1}{3}} \cdot \left(\frac{k_{III} q^2}{D}\right)^{\frac{1}{2}}}$$

Van Krevelen and Hoftijzer stated that, as the rate of absorption was directly proportional to the unreacted amine concentration (a fact confirmed by Fig. 5), the reaction must be assumed to be of the third order, k_I, the first order reaction velocity constant being replaced by $k_{III} q^2$, *in* the Hatta number.

Methods of Calculation

It was decided that the use of this equation might provide some interesting food for thought, but, before the results are given, it is necessary to explain the methods by which the relevant items were calculated. This will be done in the sequence in which they arise in the equation.

(A) Sherwood Number $\left[\frac{k''_L}{D}\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}}\right]$

(i) The liquid-film mass-transfer coefficient k''_L.

In the case of absorption accompained by chemical reaction (i.e., absorption of carbon dioxide by solutions of diethanolamine) this was calculated by dividing the weight of gas absorbed, found experimentally, by the product of the interfacial area and the mean driving force of physically dissolved gas. The driving force was calculated using carbon dioxide-water solubility data. To calculate X_{Ai}, the concentration of physically-dissolved gas at the interface, it was necessary to correct the value for pure water for the decreased solubility due to the presence of the solute molecules at the interface. This was done by evaluating a "molecular weight" for the solution, the values of X_{Ai} then being calculated using this molecular weight. Actually the mean driving force is equal to this value of X_{Ai} (using the mean partial-pressure of carbon dioxide in the gas stream), the concentration of free, uncombined carbon dioxide in the liquid being taken as zero.

(2) Diffusivity D

This was calculated in each case by the equation:

$$\frac{D\mu}{T} = \text{constant} \qquad \ldots.(8)$$

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* Continued from *British Chemical Engineering*, 1957, **2**, 16.

† Chemical Engineering Department, King's College, University of London.

General Correlation of Experimental Data.

TABLE 2. Tabulated Calculations for 0.51N Diethanolamine Solution.

Run No.	Re No.	$Re^{0.7}$	X_{Ai} lb CO_2/ft^3	k''_L lb/hr ft^2 lb/ft^3	$Sh = \frac{k''_L}{D}\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}$	q, lb mols./ft^3	$\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}$	$\frac{\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}}{C_{Ai}^{\frac{1}{3}}}$	$Ha = \frac{Sh}{C_{III}Re^{0.7}Sc^{\frac{1}{3}}}$
q calculated on basis of 1 mol $CO_2 \equiv$ 2 mols amine									
1–1	211	42.3	0.118	3.48	11.1	0.0219	0.000521	0.00374	3.03
1–2	291	51.6	0.122	4.34	13.9	0.0226	0.000538	0.00385	3.10
1–3	347	60.0	0.119	4.82	15.4	0.0234	0.000557	0.00399	2.97
1–4	131	30.3	0.120	2.62	8.4	0.0193	0.000460	0.00329	3.21
1–5	178	37.7	0.115	3.47	11.1	0.0199	0.000474	0.00345	3.40
1–6	159	34.8	0.112	3.32	10.6	0.0193	0.000458	0.00336	3.52
1–7	266	49.8	0.113	4.63	11.0	0.0213	0.000506	0.00371	2.55
1–8	452	72.0	0.121	5.65	18.1	0.0241	0.000574	0.00410	2.90
1–9	246	47.1	0.111	4.65	14.9	0.0207	0.000493	0.00364	3.64
1–10	151	33.5	0.112	1.44	4.6	0.0102	0.000242	0.00177	1.59
1–11	112	27.1	0.125	1.09	3.5	0.00975	0.000232	0.00164	1.49
1–12	213	42.9	0.120	1.70	5.5	0.0108	0.000256	0.00183	1.50
1–13	272	50.7	0.125	2.07	6.6	0.0109	0.000259	0.00183	1.51
1–14	139	31.6	0.119	1.28	4.1	0.0103	0.000244	0.00175	1.50
1–15	365	62.2	0.120	2.40	7.7	0.0116	0.000275	0.00197	1.43
1–16	452	72.0	0.119	2.69	8.6	0.0121	0.000288	0.00207	1.38
2–1	135	31.0	0.0475	2.28	7.3	0.013	0.000308	0.00301	2.72
2–5	400	66.2	0.0595	3.61	11.5	0.01475	0.000351	0.00318	2.01
2–23	111	27.0	0.0555	3.66	11.7	0.0216	0.000514	0.00476	5.00
2–25	368	62.5	0.0516	5.86	18.7	0.0268	0.000638	0.00607	3.46
2–27	239	46.0	0.0535	3.65	11.7	0.0177	0.000422	0.00396	2.94
2–30	490	76.0	0.0540	5.03	16.1	0.0197	0.000469	0.00438	2.44
3–1	173	36.9	0.0243	3.46	11.1	0.0164	0.000391	0.00476	3.47
3–4	362	62.0	0.0210	5.54	17.7	0.0175	0.000416	0.00533	3.30
3–7	515	78.5	0.0209	5.43	17.4	0.01195	0.000285	0.00364	2.56
3–10	294	53.6	0.0216	5.62	18.0	0.0289	0.000688	0.00872	3.88
3–14	493	76.5	0.0231	6.05	19.4	0.0298	0.000710	0.00880	2.92
3–17	269	50.0	0.0241	4.49	14.4	0.01935	0.000460	0.00561	3.32
3–23	227	44.2	0.0206	6.12	19.6	0.0275	0.000655	0.00845	5.11
3–24	211	42.4	0.0237	4.97	15.9	0.0186	0.000442	0.00544	4.33
3–25	211	42.4	0.0226	3.34	10.7	0.0119	0.000283	0.00353	2.91
3–26	211	42.4	0.0245	2.03	6.5	0.00345	0.000082	0.00100	1.77
q calculated on basis of 1 mol $CO_2 \equiv$ 1 mol of amine (% conversion > 70%)									
1–17	128	30.0	0.115	1.02	3.3	0.0178	0.000425	0.00308	1.26
1–18	190	39.2	0.109	1.32	4.3	0.0181	0.000431	0.00320	1.25
1–19	294	53.8	0.111	1.82	5.83	0.0185	0.00044	0.00324	1.25
1–20	464	73.9	0.108	2.51	8.05	0.0187	0.000445	0.00330	1.26
1–21	119	28.3	0.116	0.85	2.72	0.0178	0.000424	0.00307	1.11
1–22	142	32.1	0.117	0.52	1.67	0.0105	0.000250	0.00180	0.60
1–25	306	55.1	0.113	0.83	2.65	0.0112	0.000267	0.00195	0.55
1–28	240	46.2	0.115	0.64	2.04	0.0111	0.000264	0.00192	0.51
1–31	220	43.3	0.113	1.24	3.99	0.0163	0.000387	0.00283	1.06
1–34	338	58.3	0.115	1.57	5.03	0.0167	0.000397	0.00288	0.996
1–37	154	33.9	0.132	0.27	0.88	0.00615	0.000146	0.00101	0.298
1–35	127	29.7	0.115	0.205	0.656	0.00580	0.000138	0.00100	0.255
1–38	284	52.1	0.124	0.392	1.25	0.00625	0.000149	0.00106	0.278
q calculated on basis of 1 mol $CO_2 \equiv$ 1 mol of amine (% conversion > 70%)									
2–13	211	42.3	0.0591	1.70	5.46	0.01525	0.000362	0.00328	1.49
2–8	232	45.3	0.0591	2.11	6.8	0.0203	0.00048	0.00435	1.72
2–10	128	29.8	0.0549	1.51	4.9	0.0198	0.00047	0.00438	1.88
2–16	311	55.8	0.0565	2.58	8.25	0.0156	0.000371	0.00342	1.71
2–19	132	30.4	0.0592	1.00	3.21	0.0117	0.000279	0.00252	1.22
2–21	110	26.9	0.0586	0.911	2.92	0.01175	0.00028	0.00255	1.25
3–19	104	25.8	0.0244	2.72	8.73	0.01835	0.000437	0.00533	3.91
3–22	446	71.9	0.0230	5.11	16.3	0.01930	0.000460	0.00571	2.63
3–28	211	42.3	0.0238	2.89	9.26	0.01790	0.000426	0.00522	2.53
3–31	427	69.9	0.0229	3.32	10.6	0.01830	0.000435	0.00540	1.76

Information: 0.51 N diethanolamine solution contains 0.03185 lb mol amine/cu. ft of solution; $X_{Ai} = p/H \times 147$ **lb** CO_2**/cu. ft (**H **in ats/mol/mol);** $D_{CO_2-DEA} = 0.55 \times 10^{-4}$ **sq. ft/hr;** $D^{\frac{1}{3}} = 74 \times 10^{-4}$ **ft/hr**$^{\frac{1}{3}}$**;** $\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} = 1.76 \times 10^{-4}$ **ft;** $\left(\frac{\mu}{\varrho D}\right)^{\frac{1}{3}} = 9.5$ **(assumed constant); 0.490 lb** $CO_2/ft^3 = 70\%$ **conversion.**

the values for water being used as the basis:

$$D = 0.000069 \text{ ft.}^2/\text{hr}, \mu = 1.0 \text{ cp}, T = 293^\circ K.$$

(3) Viscosity, μ

The values of the viscosity were those used in the evaluation of the Reynolds numbers during the course of the experimental work based on the authors' own determinations and on Cryder and Maloney's data.[8] Actually, for the purposes of this semi-empirical correlation, it was decided that for solutions of 0.51N and 2.0N, no appreciable error would result if a constant value were assumed. for the solution of 3.5N and 5.0N, however, the viscosity showed a considerably greater dependence on the carbon dioxide content of the solution, and it was decided that, for these solutions, this simplification could not be safely adopted.

(4) Density ρ

Values of the density ρ were evaluated and assumed approximately constant for each normality of solution.

(*B*) *Constant* c

The constant c, was evaluated under conditions such that the Hatta number was equal to unity (i.e., for physical absorption). The authors' experiments on the absorption of carbon dioxide in water were used, the results being expressed by the empirical equation:

$$k'_{L30} = 0.048\,\Gamma^{0.7} \quad \ldots\ldots(2)$$

It is seen that the exponent of the liquor rate (and, therefore, the Reynolds number) is 0.7 as opposed to the two-thirds power proposed by Van Krevelen and Hoftijzer[23, 24] and so it was necessary to adopt 0.7 as the exponent on the Reynolds number in the latter's equation. Equation (2) was then substituted in Equation (7), incorporating this modification:

$$\frac{0.048\,\Gamma^{0.7}}{D} \cdot \left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} = c\left(\frac{4\Gamma}{\mu}\right)^{0.7} \cdot \left(\frac{\mu}{\rho D}\right)^{\frac{1}{3}} \quad \ldots\ldots(9)$$

From this expression, c was found to be equal to 0.00912.

Stephens and Morris[21] found that, below a Reynolds number of 60, the exponent of the liquor rate (and hence also the Reynolds number) should be 0.5. Experiments on the CO_2-water system were not possible at this low Reynolds number, but an equation can be derived assuming the exponent to change to 0.5 at this value. This is as follows:

$$k'_{L30} = 0.0984\,\Gamma^{0.5} \quad \ldots\ldots(10)$$

TABLE 3. Tabulated Calculations for 2.0 N Diethanolamine Solution.

Run No.	Re No.	$Re^{0.7}$	X_{Ai} lb CO_2/ft^3	K''_L lb/hr ft^2 lb/ft^3	$Sh = \frac{k''_L}{D}\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}}$	q, lb mols./ft^3	$\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}$	$\frac{\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}}{C_{Ai}^{\frac{1}{3}}}$	$Ha = \frac{Sh}{C_{Ai}Re^{0.7}Sc^{\frac{1}{3}}}$
q calculated on basis of 1 mol $CO_2 \equiv$ 2 mols of amine									
4–1	77.9	21.0	0.0879	8.89	87.5	0.0807	0.0042	0.0344	30.7
4–4	206	41.6	0.0879	12.6	124.4	0.0930	0.0048	0.0381	22.0
4–7	46.8	6.82	0.0831	5.6	55.2	0.0637	0.0033	0.0267	26.4
4–10	55.5	7.42	0.0853	6.6	65.3	0.0645	0.0034	0.0273	28.6
4-13	166	35.9	0.0909	7.1	69.8	0.055	0.00286	0.0225	14.3
5–1	107	26.3	0.0430	8.86	87.4	0.0738	0.00384	0.0388	24.4
5–4	234	45.8	0.0467	10.9	107.7	0.0772	0.00401	0.0392	17.3
5–7	242	43.8	0.0456	10.1	99.7	0.059	0.00307	0.0303	16.8
6–1	105	26.0	0.0209	10.4	102.6	0.0761	0.00396	0.0509	29.0
6–4	238	46.0	0.0197	13.8	136.0	0.0785	0.00408	0.0533	21.8
6–7	230	45.0	0.0193	10.3	101.0	0.0556	0.0029	0.0381	16.5
7–1	108	25.4	0.00946	10.84	107.0	0.0820	0.00426	0.0713	31.0
7–4	58.5	7.67	0.00939	11.27	111.0	0.0802	0.00417	0.0699	47.1
7–7	71.2	19.8	0.00936	9.06	89.4	0.0625	0.00325	0.0544	33.2
8–1	104	25.8	0.00916	15.37	151.3	0.1206	0.00628	0.106	43.1
8–2	106	26.1	0.0173	14.6	143.8	0.1180	0.00615	0.0836	40.5
8–5	106	26.1	0.00909	17.23	170.0	0.1206	0.00628	0.106	47.9
8–8	107	26.3	0.0936	5.29	52.1	0.0515	0.00268	0.0209	14.6
8–14	109	26.7	0.0924	5.14	50.5	0.0697	0.00362	0.0282	13.9
8–16	105	26.0	0.0966	4.06	40.0	0.0475	0.00247	0.0191	11.3
q calculated on the basis of both assumptions (average % conversion > 70%). Figures in brackets result from calculation of q on basis of 1 mol $CO_2 \equiv$ 1 mol amine.									
4–16	53.8	7.3	0.0906	2.3	22.5	0.0329 (0.079)	0.00171 (0.0041)	0.0134 (0.0322)	10.1
4–19	220	43.8	0.0894	4.63	45.6	0.0245 (0.074)	0.00127 (0.00385)	0.0100 (0.0304)	7.7
5–10	237	45.9	0.0475	5.7	56.4	0.036 (0.080)	0.00186 (0.00416)	0.0181 (0.0406)	9.04
5–13	51.9	7.19	0.0486	3.88	38.2	0.0298 (0.077)	0.00155 (0.0040)	0.0168 (0.0388)	17.3
5–16	74.1	20.3	0.0478	2.66	26.2	0.014 (0.070)	0.00073 (0.00364)	0.0071 (0.0353)	15.3
6–10	104	26.0	0.0202	8.08	79.6	0.0356 (0.080)	0.00185 (0.00415)	0.0240 (0.0536)	22.5
6–13	161	35.0	0.0230	7.85	77.4	0.035 (0.080)	0.00182 (0.00415)	0.0226 (0.0515)	25.5
8–11	104	25.8	0.00924	6.85	67.5	0.0318 (0.078)	0.00165 (0.00405)	0.0278 (0.0681)	19.2

Information: 2.0 N diethanolamine solution contains 0.125 lb mol amine/cu. ft of solution; $X_{Ai} = p/H \times 130.3$ lb CO_2/cu. ft (H in ats/mol/mol); $D_{CO_2-DEA} = 0.277 \times 10^{-4}$ sq. ft/hr; $D^{\frac{1}{3}} = 52.5 \times 10^{-4}$ ft/hr$^{\frac{1}{3}}$. Exponent of Re No. = 0.7 when $Re > 60$; 0.5 when $Re < 60$. 1.92 lb CO_2/cu. ft = 70% conversion. $\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} = 2.73 \times 10^{-4}$ ft, $\left(\frac{\mu}{\rho D}\right)^{\frac{1}{3}} = 14.9$ (assumed constant).

TABLE 4. Tabulated Calculations for 3.5 N Diethanolamine Solution.

Run No.	Re No.	$Re^{0.7}$	X_{Ai} lb CO_2/ft³	k''_L lb/hr ft² lb/ft³	$Sh = \frac{k''_L}{D}\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}$	q, lb mols./ft³	$\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}$	$\frac{\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}\frac{q}{D^{\frac{1}{3}}}}{C_{Ai}^{\frac{1}{3}}}$	$Ha = \frac{Sh}{C_{III}Re^{0.7}Sc^{\frac{1}{3}}}$
q calculated on basis of 1 mol $CO_2 \equiv$ 2 mols amine									
9–1	44.2	6.65	0.0819	8.43	326	0.155	0.0209	0.170	92.3
9–4	108	26.3	0.0829	10.6	402	0.163	0.0217	0.176	65.8
9–7	54.0	7.33	0.0800	8.46	303	0.158	0.0202	0.166	80.4
9–11	103	25.6	0.0855	10.94	440	0.143	0.0197	0.158	72.5
9–14	34.7	5.89	0.0825	6.93	265	0.134	0.0179	0.145	85.5
9–17	42.0	6.47	0.0867	5.69	238	0.099	0.0141	0.112	67.6
9–20	71.9	19.9	0.0835	7.31	310	0.102	0.0146	0.118	64.0
9–23	19.7	4.45	0.0817	3.54	146	0.096	0.0135	0.110	60.5
9–26	31.1	5.59	0.0854	3,31	152	0.073	0.0111	0.089	47.9
9–27	19.8	4.45	0.0840	3.24	149	0.068	0.0104	0.084	58.9
9–29	46.4	6.81	0.0848	4.31	201	0.074	0.0113	0.091	51.9
10–1	44.7	6.68	0.0393	10.1	388	0.150	0.0200	0.208	110.0
10–4	69.7	19.5	0.0393	11.8	430	0.152	0.0197	0.204	96.4
10–7	88.1	23.0	0.0448	10.6	482	0.142	0.0213	0.212	83.6
10–10	17.9	4.24	0.0449	6.25	286	0.132	0.0200	0.199	119.0
10–13	100	25.1	0.0420	11.1	466	0.121	0.0172	0.175	77.1
10–16	40.3	6.35	0.0450	7.05	328	0.093	0.0142	0.141	90.5
10–18	23.6	4.85	0.0448	5.78	277	0.090	0.0140	0.139	99.3
11–1	41.7	6.43	0.0173	12.1	529	0.154	0.0225	0.308	148.0
11–4	22.4	4.74	0.0154	12.7	500	0.150	0.0204	0.289	198.0
11–7	34.9	5.90	0.0153	13.6	520	0.153	0.0205	0.292	167.0
11–10	30.3	5.51	0.0171	10.9	506	0.095	0.0145	0.199	161.0
11–13	17.0	4.13	0.0170	9.45	440	0.092	0.0141	0.193	187
11–16	94.5	24.1	0.0156	17.4	700	0.139	0.0191	0.269	122
11–19	29.4	10.7	0.0167	14.0	572	0.134	0.0187	0.258	98.8
12–1	44.0	6.62	0.0090	13.7	565	0.168	0.0236	0.399	157
12–4	60.1	7.77	0.0088	14.9	624	0.168	0.0238	0.405	141
12–7	19.4	4.40	0.0086	14.4	594	0.163	0.0228	0.392	248
12–10	35.0	5.91	0.00785	17.1	689	0.141	0.0195	0.346	216
12–13	43.8	6.60	0.00837	15.9	645	0.096	0.0133	0.231	181
12–16	84.0	22.1	0.00751	18.2	721	0.120	0.0164	0.295	139
12–18	60.6	17.6	0.00805	15.8	635	0.119	0.0164	0.289	152

Information: 3.5 N diethanolamine solution contains 0.219 lb mol of amine/cu. ft of solution; $X_{Ai} = p/H \times 117.7$ lb CO_2/cu. ft (H in ats/mol/mol/; $D_{CO_2-DEA} = 0.57 \times 10^{-6} \times T/\mu$ sq.ft/hr (T in °K, μ in lb/ft hr); $\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} = \mu^{\frac{1}{3}}/1.229 \times 10^4$ ft; $\left(\frac{\mu}{\varrho D}\right)^{\frac{1}{3}} = 29.7\left(\frac{\mu^2}{T}\right)^{\frac{1}{3}}$ (ϱ taken as 66.8 lb/cu. ft). Exponent of Re No. = 0.7 when $Re > 60$, 0.5 when $Re < 60$. No experiments carried out in which % conversion > 70%.

Substitution of this in Equation (7) and changing the exponent of the Reynolds number to 0.5 gives $c = 0.0206$. Summarising:

For $Re\ No. > 60$: $c = 0.00912$ (exponent of $Re\ No. = 0.7$)
For $Re\ No. < 60$: $c = 0.0206$ (exponent of $Re\ No. = 0.5$)

(C) Reynolds Number $\left(\frac{4\Gamma}{\mu}\right)$

This group was readily calculable.

(D) The Schmidt Number $\left(\frac{\mu}{\varrho D}\right)$

For experiments involving the use of solutions of 0.51N and 2.0N, the Schmidt number could be assumed to be constant without sensible error, especially in view of the fact that the correlation involves the one-third power of this function. For solutions of 3.5N and 5.0N, however, this assumption was not made, values of the function being evaluated for each experiment. The means by which the relevant values of the terms involved were calculated have been explained already.

(E) The Hatta Number

$$\left[\frac{\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} \cdot \left(\frac{k_{III}\, q^2}{D}\right)^{\frac{1}{2}}}{\tan h \left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} \cdot \left(\frac{k_{III}\, q^2}{D}\right)^{\frac{1}{2}}}\right]$$

This function is not directly calculable, due to the fact that k_{III} the pseudo third-order reaction velocity-constant is unknown. Van Krevelen and Hoftijzer[24] had obtained an approximate correlation of the results of Cryder and Maloney[8] by plotting

$$Ha\left[= \frac{Sh}{c\, Re^{\frac{1}{2}} . Sc^{\frac{1}{3}}}\right] \text{ vs } \left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} \cdot \frac{q}{D^{\frac{1}{3}}}$$

To follow this procedure, it was necessary to make a suitable definition of q, the residual free amine concentration. The definition of q given by Van Krevelen and Hoftijzer[24] is incorrect. These authors defined it as "the initial amine concentration minus half the concentration of dissolved carbon dioxide". A study of the reaction equations will reveal the fact that for the carbonate and bicarbonate formation, 1 mol of carbon dioxide will react with respectively two mols and one mol of dissolved amine. Thus it was decided that under conditions of large excess of free, unreacted amine (i.e., at low degrees of conversion) q may safely be approximated by assuming the first reaction (carbonate formation) to predominate. An arbitrary limit of 70% conversion of the amine to its carbonates was adopted, above which this assumption was felt to be unsafe. With this assumption, q was calculable, being equal to the total concentration of amine minus twice the concentration of dissolved carbon dioxide, in molar units. Above the arbitrary deadline of 70% conversion, q was calculated from the equation involving bicarbonate formation, it is then equal to the total amine concentration minus (one times) the concentration of dissolved carbon dioxide. This definition is not correct, of course, the factor by which the carbon dioxide concentration must be multiplied lying between two and one. The factor will only approach

one at very high degrees of conversion of the amine. However, the definition was adopted, the resulting values being inserted in the ensuing tables. Actually, the difficulty was encountered only when using solutions of 0.51 N and 2.0 N, the conduction of experiments with 3.5 N and 5.0 N at a degree of conversion in excess of 70% not being possible.

Correlation of Results

After defining the terms, an attempt could now be made to correlate the experimental results on the basis of a modified Van Krevelen-Hoftijzer equation:

$$\frac{k''_L}{D}\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} = c\left[\frac{4\Gamma}{\mu}\right]^x \cdot \left[\frac{\mu}{\rho D}\right]^{\frac{1}{3}} \cdot \left[\frac{\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} \cdot \left(\frac{k_{III}\, q^2}{D}\right)^{\frac{1}{3}}}{\tanh\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}}\left(\frac{k_{III}\, q^2}{D}\right)^{\frac{1}{3}}}\right] \quad \ldots (11)$$

where $c = 0.00912$ when $x = 0.7$ (Re No. > 60);
$c = 0.0206$ when $x = 0.5$ (Re No. < 60).

Approximately one-third of all the experimental results were used, the values of the various functions being shown in Tables 2 to 5, for the four normalities of solution used in the experimental work. In the course of plotting $Ha \left[= \frac{Sh}{c\, Re^x . Sc^{\frac{1}{3}}}\right]$ vs $\left[\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} \frac{q}{D^{\frac{1}{3}}}\right]$ it was noted that generally for a given value of the function $\left[\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} \cdot \frac{q}{D^{\frac{1}{3}}}\right]$ the Hatta number decreased with increasing values of X_{Ai}, the equilibrium concentration of physically-dissolved carbon dioxide. It was found by trial and error that the scatter of the points could be most materially reduced by dividing the values of the function $\left[\left(\frac{\mu^2}{g\rho^2}\right)^{\frac{1}{3}} \cdot \frac{q}{D^{\frac{1}{3}}}\right]$ by $C_{Ai}^{\frac{1}{3}}$. The resulting graph is shown in Fig. 9. In view of the various assumptions made as outlined above, and the semi-empirical nature of the equation on which the correlations are based, the graphs are satisfactory.

The slope of the lines is seen to be approximately that of unity, in agreement with the chart given by Van Krevelen and Hoftijzer[24] from the data of Cryder and Maloney.[8] The fact that the direct proportionality does exist is proof that the peculiar dependence of the mass-transfer coefficient on the normality of the solution, as shown in Fig. 8 for example, is due entirely to the influences of viscosity and diffusivity.

The occurrence of a third-order reaction is most unlikely and Van Krevelen and Hoftijzer[24] concluded (from the fact that they found k_{III}, the third-order reaction velocity constant, to be nearly independent of temperature change) that the reaction was in reality a succession of two second-order reactions, the first (involving the reaction of one molecule of carbon dioxide with one molecule of amine to form the bicarbonate) being more rapid than the second (involving the reaction of that molecule of bicarbonate with a further molecule of unreacted amine to form the carbonate). In that case, these authors stated, k_{III} would be the product of an equilibrium constant and a reaction velocity constant, with the possibility that the temperature influence would cancel itself.

The results indicate that the probable mechanism of CO_2 absorption in diethanolamine is a combination of diffusion

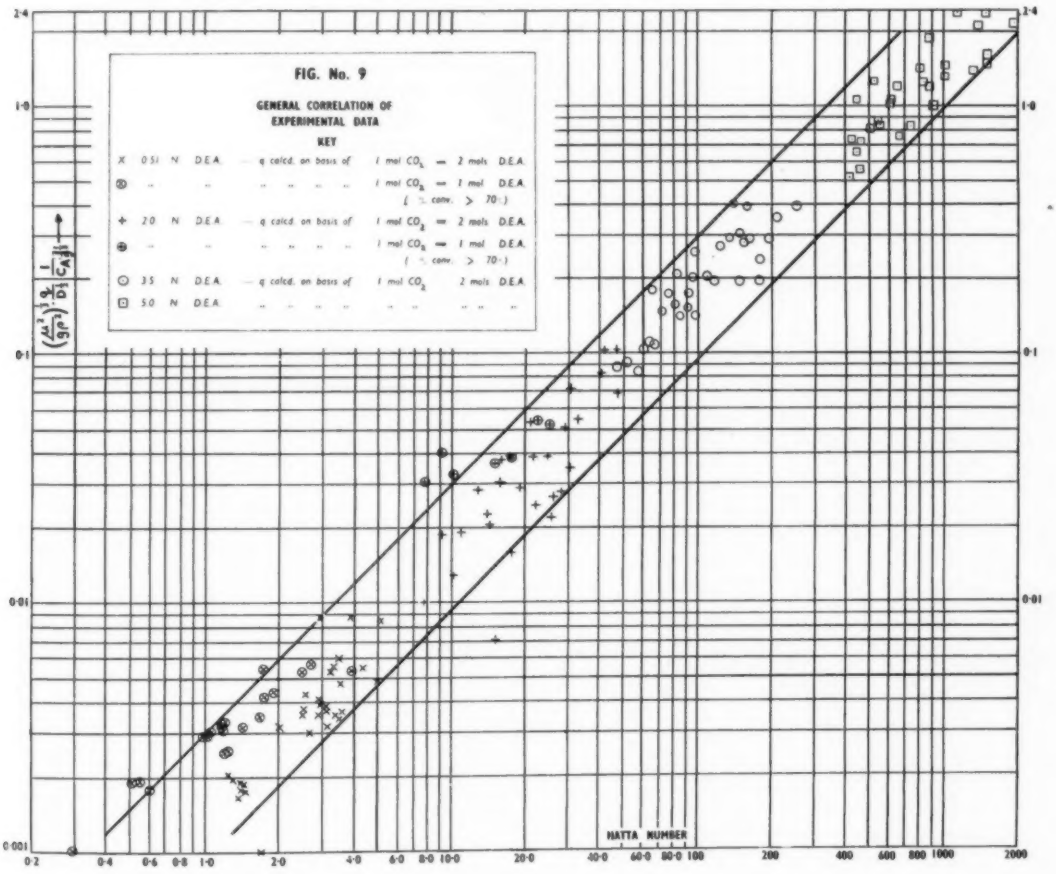
FIG. No. 9
GENERAL CORRELATION OF EXPERIMENTAL DATA
KEY
0·51 N D.E.A. — q calcd. on basis of 1 mol CO2 = 2 mols D.E.A.
1 mol CO2 = 1 mol D.E.A. (< conv. > 70%)
2·0 N D.E.A. — q calcd. on basis of 1 mol CO2 = 2 mols D.E.A.
1 mol CO2 = 1 mol D.E.A. (< conv. > 70%)
3·5 N D.E.A. — q calcd. on basis of 1 mol CO2 = 2 mols D.E.A.
5·0 N D.E.A.
HATTA NUMBER

TABLE 5. Tabulated Calculations for 5.0 N Diethanolamine Solution.

Run No.	Re No.	$Re^{0.7}$	X_{Ai} lb CO_2/ft³	k''_L lb/hr ft² lb/ft³	$Sh = \frac{k''_L}{D}\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}}$	q, lb mols./ft³	$\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} \frac{q}{D^{\frac{1}{3}}}$	$\frac{\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} \frac{q}{D^{\frac{1}{3}}}}{C_{Ai}^{\frac{1}{3}}}$	$Ha = \frac{Sh}{C_{III} Re^{0.7} Sc^{\frac{1}{3}}}$
q calculated on basis of 1 mol $CO_2 \equiv$ 2 mols of amine									
13–1	16.9	4.11	0.0752	12.8	2200	0.283	0.107	0.898	558
13–4	7.4	2.72	0.0835	7.85	1830	0.276	0.129	1.042	619
13–7	29.1	5.40	0.0839	12.5	2850	0.296	0.137	1.107	446
13–10	6.4	2.53	0.0835	7.35	1720	0.274	0.129	1.047	625
13–13	18.1	4.26	0.0768	11.9	2500	0.232	0.102	0.849	561
13–16	27.5	5.23	0.0745	13.8	2680	0.235	0.097	0.816	509
13–19	12.7	3.56	0.0781	7.43	1670	0.194	0.089	0.735	437
13–22	18.5	4.30	0.0756	9.70	2190	0.190	0.087	0.728	474
13–25	7.4	2.72	0.0773	5.67	1330	0.170	0.0805	0.668	448
13–28	16.3	4.04	0.0782	8.20	2060	0.132	0.0652	0.537	456
13–31	7.7	2.78	0.0758	5.27	1260	0.126	0.0604	0.505	411
14–1	13.5	3.67	0.0384	14.4	3460	0.259	0.125	1.310	852
14–4	33.7	5.80	0.0419	13.6	3440	0.269	0.133	1.357	529
14–7	19.5	4.41	0.0410	13.9	3210	0.263	0.123	1.261	669
14–10	5.9	2.43	0.0366	7.99	1760	0.157	0.071	0.756	683
14–13	17.6	4.20	0.0378	14.50	3390	0.165	0.078	0.824	740
14–16	7.7	2.78	0.0366	11.0	2890	0.184	0.094	1.000	906
15–1	13.3	3.65	0.0147	16.2	3390	0.202	0.0885	1.274	890
15–4	17.0	4.13	0.0138	21.3	4450	0.203	0.0890	1.310	1030
15–7	22.6	4.74	0.0144	17.8	4170	0.206	0.0975	1.412	807
15–10	14.4	3.79	0.0165	19.8	6240	0.169	0.098	1.362	1340
15–13	3.2	1.79	0.0170	10.1	3620	0.160	0.101	1.389	1570
15–16	16.0	4.00	0.0158	15.5	5050	0.172	0.102	1.434	1010
15–19	23.8	4.89	0.0162	17.4	5200	0.236	0.132	1.843	889
16–1	11.1	3.34	0.0079	20.8	6330	0.236	0.133	2.360	1570
16–4	21.5	4.63	0.0082	20.7	6300	0.238	0.134	2.358	1130
16–7	16.1	4.02	0.0075	23.7	7070	0.210	0.118	2.138	1470
16–10	18.8	4.34	0.0083	30.8	10410	0.208	0.126	2.202	1910
16–13	5.1	2.26	0.0073	16.1	4200	0.179	0.0915	1.665	1630

Information: 5.0 N diethanolamine solution contains 0.312 lb mol of amine/cu. ft of solution; $X_{Ai} = p/H \times 101.1$ lb CO_2/cu. ft (H in ats/mol/mol); $D_{CO_2-DEA} = 0.57 \times 10^{-6} \times T/\mu$ sq. ft/hr (T in °K, μ in lb/ft hr); $\left(\frac{\mu^2}{g\varrho^2}\right)^{\frac{1}{3}} = \mu^{\frac{1}{3}}/1.252 \times 10^4$ ft; $\left(\frac{\mu}{\varrho D}\right)^{\frac{1}{3}} = 29.5\left(\frac{\mu^2}{T}\right)^{\frac{1}{3}}$ (ϱ taken as 68.5 lb/cu. ft).

Exponent of Re No. = 0.7 when $Re > 60$, 0.5 when $Re < 60$. Constant $C_{III} = 0.0206$ when $Re < 60$, 0.00912 when $Re > 60$. No experiments conducted for which % conversion > 70 %.

and chemical reaction, with chemical reaction as the controlling factor. This we would expect, because the activation energy for a non-ionic reaction such as this, is much greater than that required by molecular diffusion. The chemical reaction is of the second order and involves interaction between dissolved CO_2 with hydroxyl ions.

Recently, Van Krevelen and Hoftijzer[25] have devised a method by which, they claim, the overall rates of interphase mass exchange may be predicted for any second-order reaction.

Summary

The rates of absorption of carbon dioxide in water and in aqueous solutions of diethanolamine have been measured using the standard disc-column developed by Stephens and Morris.[21] As this column presents a fixed interfacial area for interphase contact, it is believed that the results obtained, presented as K_G values, are of greater fundamental value than previously published data based upon investigations carried out using towers filled with commercial packings. The following range of variables was covered:

Amine normalities ...	0.51, 2.0, 3.5 and 5.0N
Per cent. conversion to amine carbonates	Zero up to a suitable value, consistent with experimental accuracy
Liquor rate	70 to 380 lb/hr ft of wetted perimeter
Gas concentration ...	Approximately 10, 20, 50 and 100% CO_2 (total pressure=1 atm)

The dependence of the rate of absorption on the above variables was found to agree generally with the findings of Cryder and Maloney[8] working on the same system.

Deterioration of the amine solution is effected by the regeneration process, and it is suggested that this is due to some thermal decomposition of the amine.

A satisfactory correlation of the results was obtained on the basis of a modified Van Krevelen-Hoftijzer equation:[25]

$$Sh = c.\ Re^{(0.5 \text{ or } 0.7)}\ Sc^{\frac{1}{3}}\ Ha.$$

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The ceramic discs used in the investigations were kindly supplied, on request, by I.C.I., Billingham Division.

General view of the plant of Laporte Titanium Ltd., at Stallingborough. In the foreground are the concrete acid-storage tanks.

Fuel Efficiency at Laporte, Stallingborough

THE problem confronting the management of Laporte, at Stallingborough, was how to run the factory's steam-raising plant economically when, because of the batchwise nature of many of the chemical processes, the demand for steam is a fluctuating one. Another factor that had to be considered was that the boilers frequently have to operate at a steaming rate well below their rated capacity. The waste-heat boiler of the contact sulphuric acid plant, which supplies the acid used in the titanium dioxide extraction process, is a further complicating factor since, occasionally, for maintenance reasons, it is necessary to close down this section of the plant. Such action places a sudden additional load upon the main boilers through the interruption of the steam supply.

A further incentive to efficiency of steam usage and production is the fact that steam constitutes an appreciable proportion of the total cost of the main product of the factory.

A group of super Lancashire boilers, each one capable of producing about 13,700 lb/hr of steam from and at 212°F, provides the main steam supply, the pressure being 130 psig. In addition, the waste-heat boiler generates about 12,000 lb/hr at a pressure of 375 psig. This latter steam supply passes out of a turbine driving an alternator set at an exhaust pressure of 25 psig; the electrical output at the alternator is around the 275-kWh mark. The 130 psig steam from the Lancashire boilers is used for high-pressure process heating and a part is reduced to 25 psig and is joined by the exhaust from the turbine set.

The boilers are fitted with economisers, superheaters and mechanical chain-grate stokers to which the fuel is fed by means of an arrangement of Redler conveyors and chutes. Make-up feed water is treated in an ion-exchange water-softener plant.

Improved Steam-to-Coal Ratio

The fuel used is a low-grade washed slack of C.V. 11,500 Btu/lb and has an ash content of 11%. In the early stages of boiler operation, the difficulties created by the load fluctuations and the necessity for the boilers in use to operate for periods at a low-load contributed a rather low steam-to-coal ratio, which averaged around 5.5:1.

The advice of the National Industrial Fuel Efficiency Service (NIFES) was sought as to the best methods of raising this ratio and, as a result, a factor of 7.5 was attained. This figure, moreover, does not represent the limit to which it can be raised; it is expected that a factor of 7.8 will be readily accomplished.

The measures taken to raise the steam-to-coal ratio concerned the following:

(1) Steam trapping.
(2) Blow-down heat recovery.
(3) Flue-gas flow at economiser.
(4) Condensate-return system improvements.
(5) Exhaust steam utilisation from feed pump.
(6) Draught control, air leakage at boilers.
(7) Coal mixing, and feeding arrangements at boilers.
(8) Facilities for cleaning deposits from flue-gas side of tubes.
(9) Miscellaneous factors such as leakage of steam at valves, and feed water from pump glands.

These are dealt with in detail below:

Steam trapping. The aim was to reduce steam losses to a minimum. The capacities of existing traps were checked against their required capacities to make certain that they would operate satisfactorily. In addition, a system of scheduled maintenance was put into force to ensure that the traps continued to function properly.

Blow-down. Intermittent blow-down was replaced by

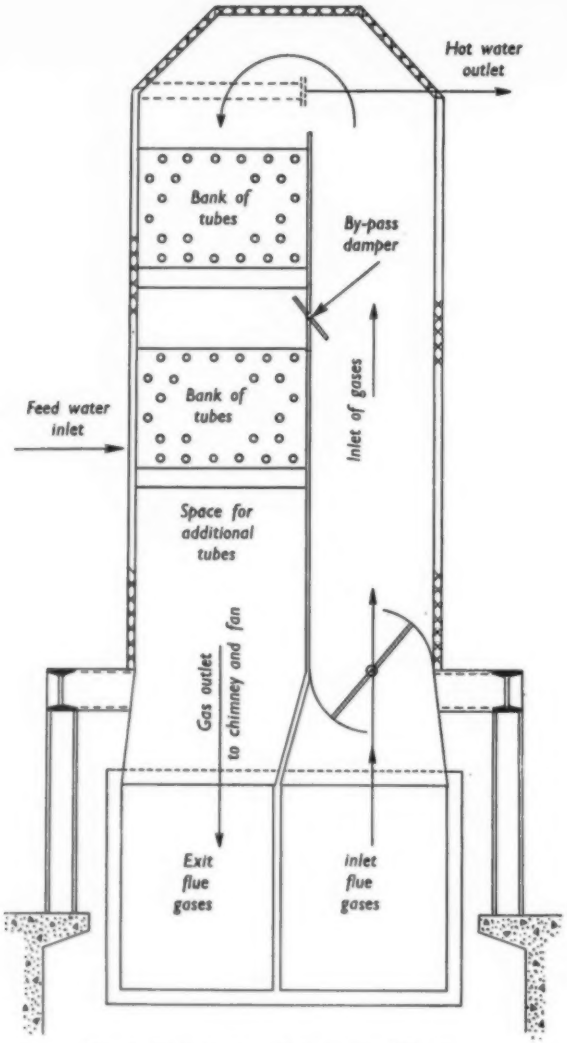


Fig. 1. Economiser damper modification.

continuous blow-down, coupled with exchange of blow-down heat to feed water by means of an exchanger. This measure gives cleaner interior boiler-heating surfaces as well as some heat recovery.

Flue-gas flow at economiser. At low loads, the rate of flow of flue gases across the economiser's external surfaces was low enough to reduce considerably the effectiveness of the latter; consequently, the overall efficiency of the boiler under low-load conditions was bound to fall considerably. In view of the poor heat-transfer conditions and the resultant poor heat extraction from the flue gases, an improvement to the economiser system was made by fitting a damper with the aim of decreasing the cross-sectional area flow of the main volume of the flue gases. The result of this change is to speed up the gas flow across the major portion of the economiser's external surface, so that at low-steaming rates the heat transfer from the flue gases to the feed water is much improved. The damper is designed to control the proportion of the gas so diverted (Fig. 1).

Condensate arrangements. Condensate at the factory has two separate sources: (a) process heating, at coils of reactors, etc.; and (b) space heating of buildings and offices.

There is no difficulty in returning condensate from the latter source (b) to the boilers. The former, however,

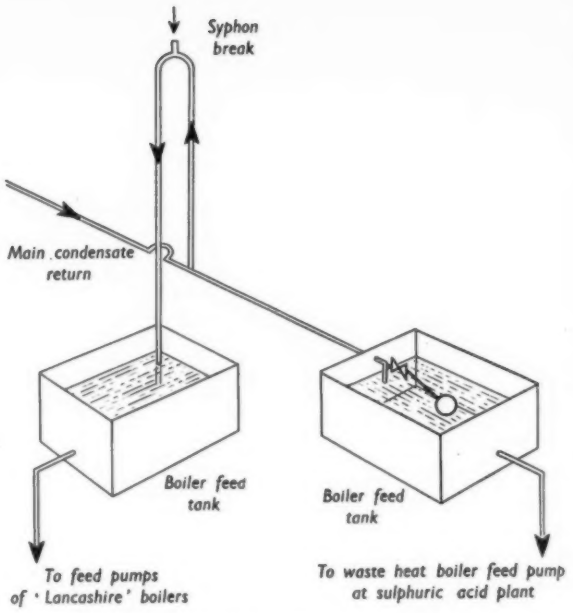

Syphon break
Main condensate return
Boiler feed tank
Boiler feed tank
To feed pumps of 'Lancashire' boilers
To waste heat boiler feed pump at sulphuric acid plant

Fig. 2. Condensate-return system.

consists of two parts, one issuing from the heating surfaces of vessels containing corrosive reagents and the other from the calandrias of evaporators and other equipment where there is no risk of leakage at the heat-transfer surfaces. Of the two, the latter only, the so-called "uncontaminated" condensate, can be returned to the boilers with safety, although, before the new measures were introduced, both were mixed. Now, however, the condensate is divided into two parts according to its source, and the "uncontaminated" condensate is returned primarily to the waste-heat boilers, and the remainder to the main range plant. Although the "contaminated" condensate is not returned to the boilers it is by no means a complete thermal loss, since it is used as a raw material in the process which, in any case, requires heat.

The condensate has to be returned to the Lancashire boilers and to the waste-heat boiler at the sulphuric acid plant. The method of balancing the supply is shown in Fig. 2, and is quite automatic in operation.

A number of other condensate-handling measures were taken. For example, in order to reduce flash losses, all condensate pipes have been grouped together into a common discharge pipe at the feed tank. The open end of this pipe is submerged below the water level to a depth of about $1\frac{1}{2}$ ft.

Feed pump exhaust. The exhaust from the pumps is now passed through coils submerged in the feed tank in order to recover latent heat without contaminating the feed water with lubricant.

Draught conditions. The investigation of the boiler operation revealed air leakage into the flues. The heat loss from this occurrence was readily eliminated. The consultants (NIFES) advised that the best indication of correct draught conditions would be the CO_2 recorder. A value of 11.5 to 12.5% CO_2 is considered to be a figure representative of economic draught conditions.

Fuel feed improvement. The fuel consists of two different varieties of coal which are mixed before feeding to the boiler furnaces. The method of mixing left something to be desired; the result of poor mixing leading inevitably to uncontrollable combustion variations at the boiler. The shortcoming also made sudden increases in steam demand more difficult to meet.

The coal feeding system in the earlier days at the plant gave a great deal of mechanical trouble, causing a shortage of fuel supply at the boilers. Part of this trouble was the failure of some of the chutes to discharge fuel to sections of the conveyor system and to the boilers. The fitting of vibrators at chutes and the use of glass lining on their interior surfaces helped to provide an uninterrupted flow of coal to the boilers.

Flue-cleaning facilities. Regular cleaning of soot and scale from the flue-gas side of the convection section of the boilers was a further practice urged by the consultants. This meant that the flue covers at the boilers had to be easily removable to give access to the tubes, and lead to mounting the covers upon hinges and the substitution of cover bolts by specially made toggle bolts (Fig. 3). These measures permit access to the tubes in a few moments. At the same time, mechanical tube-cleaning apparatus is now kept at the boiler-house for de-sooting.

Miscellaneous factors. These amounted to regular attention to valve packings, water and steam glands of the feed pump.

The effect of some of these changes upon the boiler economy is shown by the following approximate figures expressed as a potential saving of the coal consumption of 1954:

Blow-down heat recovery	0.7%
Economiser damper modification	9.5%
Feed-pump exhaust steam use	2.6%
Improved boiler control and better understanding of combustion conditions and flue gases at exit of boiler plant by the operators	16%

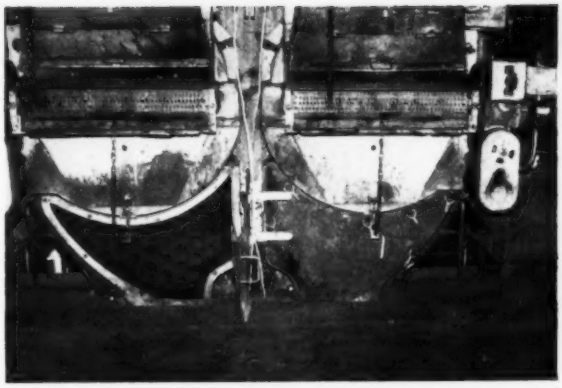


Fig. 3. The quick-opening doors which permit easy access to boiler flues.

Conclusions

The effect of the changes is worth evaluating.

Steam basis = 1000 lb/hr

$$\therefore \left(\frac{1{,}000}{5.5} - \frac{1{,}000}{7.5}\right) \times \frac{1}{2240} = 0.0216 \text{ tons/hr}$$

The annual saving on each 1000 lb/hr of steam generated = 189 tons of coal a year. For fuel costing £4 a ton the annual saving amounts, on each 1000 lb/hr of steam generated, to £756. In addition to these economies, there are the hidden savings at the process plant through the improved supply of steam.

QUANTOMETER FOR PRODUCTION CONTROL OF STEEL

PRODUCTION CONTROL OF STEEL has been carried a stage further at the Stocksbridge works of Samuel Fox & Co. Ltd., a subsidiary of United Steel, with the installation of a quantometer for routine spectrographic analysis. It is the second instrument of its kind to be installed by United Steel, whose Steel, Peech & Tozer branch were the first in the British steel industry to use a quantometer in 1955. The Stocksbridge unit—the initial production model of a modified design by Association Research Laboratories of Lausanne—is solely for the analysis of steel, including stainless and high-speed steels.

Designed for the determination of seventeen elements in ranges from a trace up to 30%, the instrument can provide an analysis for manganese, nickel, chromium, molybdenum and copper in ten to fifteen minutes from taking the sample from the furnace. By traditional methods, such an analysis would take about one hour. The actual analysis time is about four to five minutes; preparation of the sample by wet grinding to produce a smooth, flat surface takes from two to three minutes, leaving a transit time of three to six minutes, which will naturally vary according to the distance of the melting shop from the laboratory and of the furnace from the conveyor tube terminal. The critical importance of the time factor can be illustrated by the example of stainless-steel scrap melts, which cannot be analysed quickly by chemical methods during the melting period and which were hitherto entirely outside analytical control during the later stages of a heat.

Situated in an air-conditioned laboratory near the large arc furnace shop at Samuel Fox, the quantometer operates in conditions of close atmospheric control. Temperature is maintained at 70°F (± 2°F) and humidity at between 45 and 50%, thus helping to provide efficient working and the reduction of adjustment and calibration to a minimum.

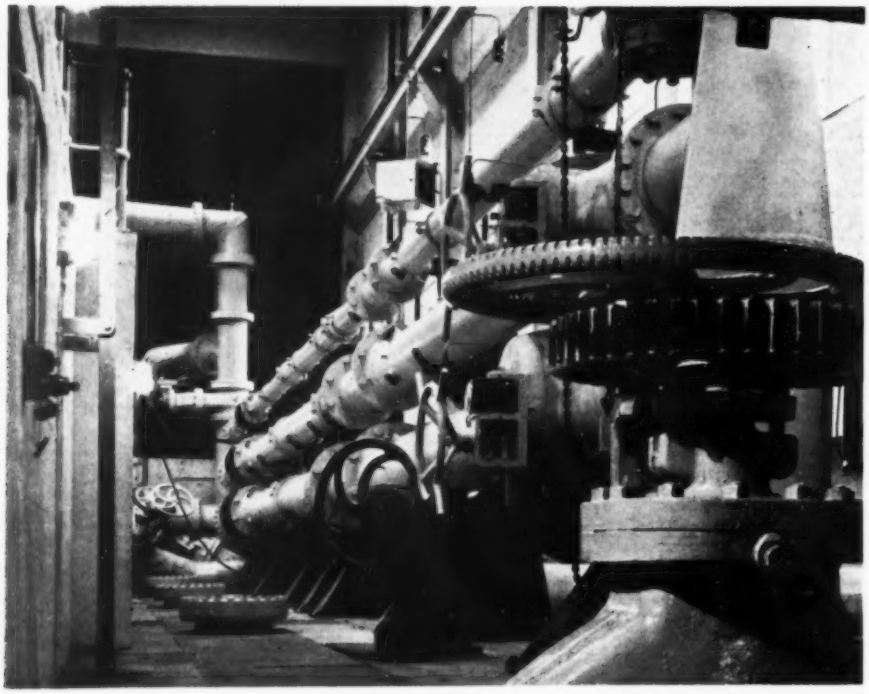
The instrument consists of three units:

(1) *The multi-source unit,* which supplies excitation conditions across the analysis gap, causing spark-like or arc-like discharges, as desired, to the sample under analysis; the inclusion of a polarity reversing switch allows the polarity of a sample to be changed very rapidly. Power for the source unit is provided by a Schlinder motor generator set, giving stability of voltage and frequency. A Foster stabiliser is also available as a stand-by.

(2) *The spectrometer,* which forms a spectrum from the light released by the discharge, enabling the wavelengths of elements in the sample to be isolated and their light energy to be transformed into electrical charges. The spectrometer consists of an aluminium mounting, of all-welded construction, which allows the diffraction grating and slit frames to be mounted on the Rowland circle. Selected wavelengths of the diffracted light are isolated by carefully positioned slits, and focused by mirrors on to photomultiplier tubes. Modifications from previous models include slit frames which fit the focal curve at all wavelengths instead of cutting it at several points, and tube plates which move in conjunction with the slit frames so that no optical misalignment results from changes in profiling.

(3) *The recording console,* which houses all the necessary high- and low-voltage power supplies, integrators, amplifier, sensitivity controls and switching circuits. In this unit, the charges from the multiplier phototubes are collected by integrator capacitors, sequentially switched to an amplifier and then recorded on a high-speed recorder. The recorder system was supplied by Trüb Taüber of Zürich.

Although the quantometer has been in operation at Samuel Fox for only a short time, the company reports that the reliability of analyses has been found to be comparable with that of standard chemical procedures.



Open hydraulic circuit for the testing of flowmeters and valves. Note the three test sections of differing pipe diameters.

CHEMICAL ENGINEERING RESEARCH AT EAST KILBRIDE

THE work of the D.S.I.R.'s research laboratory at East Kilbride deals with a variety of mechanical engineering problems, in such widely differing spheres as mechanisms, lubrication and wear, noise control, properties of materials, heat transfer and applied thermodynamics, and fluid mechanics. To some degree, all of these categories are of interest to chemical engineers, especially those of heat transfer and fluid mechanics. It is for this reason that this article reviews some of the work at the laboratory, as well as future research programmes.

Heat Transfer

Research on heat transfer has been conducted in a number of directions, including the following:

(1) The effect upon heat-transfer coefficients for fluids flowing inside pipes, of such structural discontinuities as bends, sudden constrictions and enlargements, for both viscous and turbulent regions.

(2) The heat-transfer properties of liquid metals, such as mercury.

(3) The heat-transfer properties of regenerator beds.

(4) Natural convection from vertical planes for laminar boundary-layer flow—a subject of importance in connection with heat transfer in liquid metals.

(5) An investigation of dropwise condensation.

(1) *Effect of discontinuities.* The vast majority of industrial heat exchangers employ pipes and the greater part of the existing knowledge on the heat-transfer rates refers to pipes which are straight, of uniform diameter and free from any feature tending to disturb the flow. In practice, however, fittings like bends, header boxes and entrances and exits from tube nests are common in heat-exchange equipment, with the result that the fluid flow is disturbed and abnormal heat-transfer conditions arise. Some knowledge of the effect of these discontinuities upon fluid flow is available, but very little is known about their influence upon heat-transfer rates. The Establishment has undertaken a programme of work to help bridge this gap.

The number of possible arrangements which might be investigated is unlimited, but the initial experiments are to deal with abrupt changes in pipe diameter and right-angled bends only. The experimental rigs allow investigation of the effect of diameter divergency ratios up to 1 : 1.25 for water, and to a convergence ratio of 1 : 1.5 with air. For right-angled bends, water is the test fluid.

The experimental apparatus consists of a supply of fluid, the particular discontinuity under investigation, the source of heat and a heated section of pipe, plus various instruments for measurement of flow, temperatures and heat input in order that the various energy and material balances may be made. The fluid is passed through the discontinuity, then heated in the straight section of pipe immediately downstream of it. The effect of the disturbance upon local heat-transfer rates is reflected in the temperature of the pipe, which will vary according to the magnitude of the disturbance created. A system of thermocouples fixed at close intervals along the heated length

of tube measures the temperature gradient along it, and allows the extent of any abnormal effect to be traced.

Results so far obtained with this experimental apparatus show that for high rates of flow the effect of a discontinuity is rather small and does not extend very far along a pipe. For laminar flow, however, the effect of discontinuities is quite marked and may extend along a pipe to a distance of 50 diameters or more. The effect of a divergence is much more marked than with a convergence. The work completed to date is amplified in References 1 and 2.

(2) *Heat transfer to mercury.* Heat transfer in the field of liquid and molten metals is very scanty, and general information is required about the heat-transfer properties of a very large number of fluids, including gases and liquid metals. By means of analytical methods employing dimensionless groups, it is possible to predict the behaviour of any fluid if the behaviour of four typical fluids is known. These are a gas, such as air; a mobile liquid, such as water; a more viscous liquid, such as a hydrocarbon oil; and a liquid metal. Relatively little is known about the latter, and a programme of research is being undertaken to gain further knowledge of the subject.

Heat transfer with an ordinary fluid in turbulent flow takes place mainly by convection, i.e. by radial eddying flow between points at different temperatures, and the contribution to heat transfer by conduction is negligible. Liquid metals, however, have much great thermal conductivities than liquids like water, and, as a consequence, this property plays a much more important part in heat-transfer processes involving molten metals.

In theoretical work on heat transfer by forced convection, estimations of the velocity and temperature gradients across the fluid path are necessary. This information is normally given in the terms of velocity profile and α, the ratio of eddy diffusion of heat to diffusion of momentum. This ratio gives the relationship between temperature and velocity at any point across the main flow. Both the velocity profile and α are known with sufficient accuracy for most of the fluids commonly encountered in heat-transfer practice. Thus, analytical predictions of heat-transfer rates in such instances are reasonably accurate. With liquids of high thermal conductivity, however, the temperature profile, and therefore the value of α, will differ appreciably from those found with the normal run of liquids. For this reason, predictions of heat-transfer rates for liquid metals based on the properties of normal fluids are generally higher than those found experimentally. Temperature and velocity profile measurements are to be made, using mercury as the fluid.

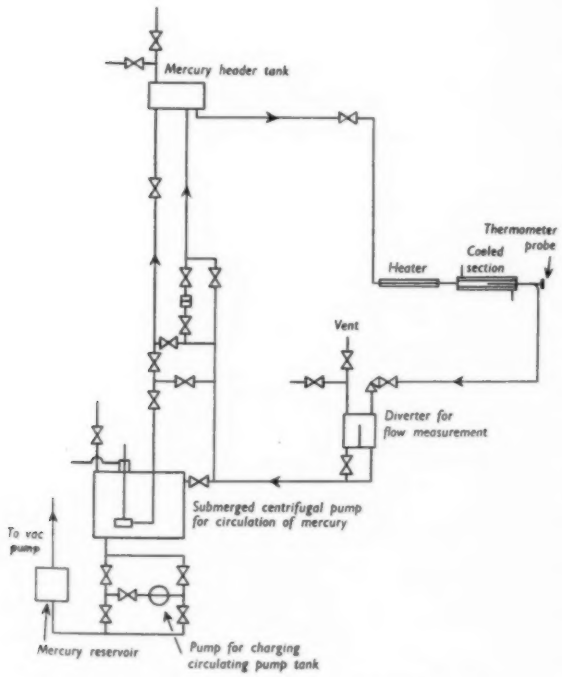


Fig. 1. Plant for determination of heat-transfer properties of mercury.

The experimental rig for this work will enable these measurements to be carried out in horizontal and vertical pipes, with the flow either upwards or downwards as desired. The pipe diameters will be about 5 in. and are greater than those employed in previous investigations. An advantage of the new set-up will be that profiles can be measured at any position along the pipe. Previous rigs used by other investigators for profile determinations permitted observations at one or two positions only.

Among the factors affecting heat-transfer rates with liquid metals is the ability of the liquid to wet the pipe-wall and its content of entrained gas; the latter causes an apparent reduction in thermal conductivity. Both these aspects of liquid-metal heat transfer are to be investigated in the main apparatus (Fig. 1). A smaller apparatus is to be set up for investigating these particular problems.

(3) *The properties of regenerator beds.* The thermal efficiency of many processes depends upon the recovery of the sensible heat content from the product or waste fluids. Many processes use regenerators for such heat recovery. Heat transferred to the packing from the outgoing fluid is transferred to the incoming fluid after the reversal of flow has taken place. This process is repeated continuously. In gas-separation processes the regenerator is used for the recovery of cold as well as for purifying the feed gases.

In order to design a regenerator, or to improve an existing design, it is necessary to know the heat-transfer coefficient between the fluid and matrix. This is difficult to determine, since it involves the measurement of the surface temperatures of packing and fluid at different positions in the matrix, and in directions both normal and parallel to the direction of flow. The usual method of measuring the heat-transfer coefficient is known as the "single blow" technique. In this a steady stream of fluid is passed through the matrix; its inlet temperature is maintained constant for a short while, and then changed suddenly to a new constant value. The temperature of the fluid at the outlet of the packing is recorded from the moment the inlet temperature is changed. The heat-transfer coefficient is then determined from the temperature-time gradient. This method has limited accuracy, and a more reasonable simulation of regenerator conditions may be obtained by varying the inlet temperature of the fluid sinusoidally so that the heat is transferred alternately to and from the matrix. For these conditions, a simple mathematical relationship exists between the amplitudes of the outlet and inlet temperatures from which the heat-transfer coefficient may be determined.

The experimental apparatus will employ a matrix consisting of a bed of steel balls. The working fluid will be air whose temperature will be varied sinusoidally by means of an electric heater. The variance of inlet and outlet air temperatures will be measured by continuously-recording resistance thermometers. Initially, the object of the experiment will be to compare results obtained by this method with those obtained by the "single blow" technique. When this has been done, the heat-transfer properties of a number of industrial regenerator packings will be determined.

(4) *Natural convection.* An equation[3] has been devised

Table 1. Comparison of Heat-transfer Coefficients (Orders of magnitude only)

Pure copper plate 3.1 mm. (0.123 in.) thick—surface vertical

Type of Condensation	Overall Heat-transfer coefficient (for water velocity of 3 m/s (10 ft/s)	Steam-side Heat-transfer coefficient (for water velocity of 3 m/s (10 ft/s)
Dropwise	11,000-14,000 W/m² °C (2000-2500 Btu/ft²h°F)	110,000-140,000 W/m² °C (20,000-25,000 Btu/ft²h °F)
Filmwise	4000-6000 W/m² °C (700-1000 Btu/ft²h °F)	8500-14,000 W/m² °C (1500-2500) Btu/ft²h °F)

for evaluating the natural convection between concentric horizontal cylinders and concentric spheres. The equation gives good agreement with experimental values when the convection contribution is less than 2% of the total heat transfer in a particular case. Another formula[4] has been developed for assessing natural convection from vertical planes for laminar boundary layer flow. This is of practical importance, because it may be applied to convection in liquid metals for which earlier formulæ are not applicable.

(5) *Promotion of dropwise condensation.* Ways and means of producing dropwise condensation are of practical importance, since this form of condensation gives much higher heat-transfer rates than those obtained from filmwise condensation. The achievement of prolonged dropwise condensation would mean cheaper condensing and evaporating equipment for a number of process plants. Table 1 gives a comparison of heat-transfer coefficients for dropwise and filmwise condensation of steam on copper.

Dropwise condensation can be produced by modifying the interfacial tensions at the metal surface by treatment of the latter with a suitable promoter. A number of chemicals are under investigation as promoters, durability of their effect being one of the most desirable properties. It is possible that this work may be extended to the dropwise condensation of other fluids.

Thermodynamic Properties

Knowledge of the thermodynamic properties of gases is continually required by chemical and other engineers. In view of this wide demand, work is being carried out on the determination of thermodynamic properties of gases. A method has been devised[5] which enables these properties to be evaluated with reasonable and useful accuracy without the necessity for making measurements over a wide range of pressures and temperatures.

Work in the Field of Fluid Mechanics

Some of the work of the division dealing with fluid mechanics has been in the field of fundamental and applied research on pumps, fans, turbines and flow problems generally. The plant available for experimental work includes open circuits for performance tests on pumps, for calibrating flow-measuring instruments, and for tests on pipes and valves. There are closed circuits for investigating the performance of pumps under cavitating conditions and, in addition, equipment is available for investigating pump designs using air as the working medium.

Flow through the open circuit is obtained by means of a head tank which, with its concertina-shaped weir of a total length of 120 ft, is able to provide a head of 45 ft ± ¼ in., over a flow range of 0 to 12,000 gpm. Interesting features of the open circuits are the weighing tanks and the diversion valves used for direct measurement of flow rate. A variable head tank is also available in which a telescopic weir is used to set the head at any value between

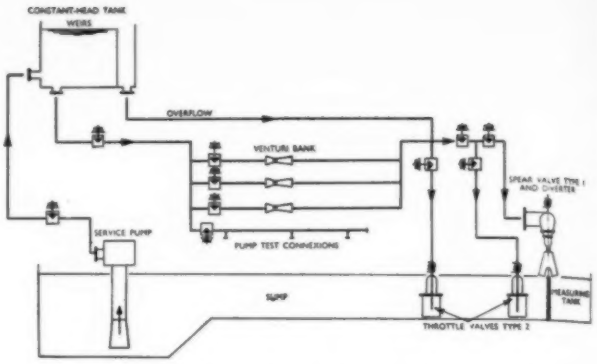


Fig. 2. Open circuit for the testing of flowmeters, etc.

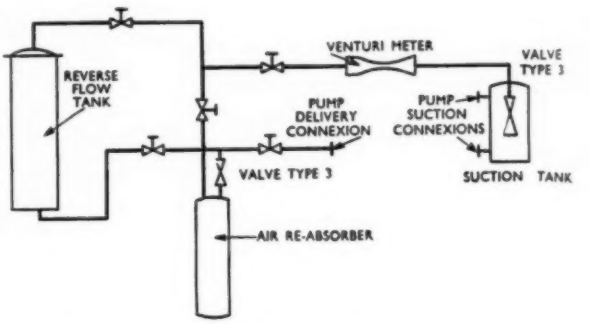


Fig. 3. Closed circuit for cavitation tests on pumps.

12 and 40 ft above sump water level. Arrangements have been made to allow pumps to be mounted above this tank in order to test their performance under suction inlet pressures down to 5 ft of water absolute.

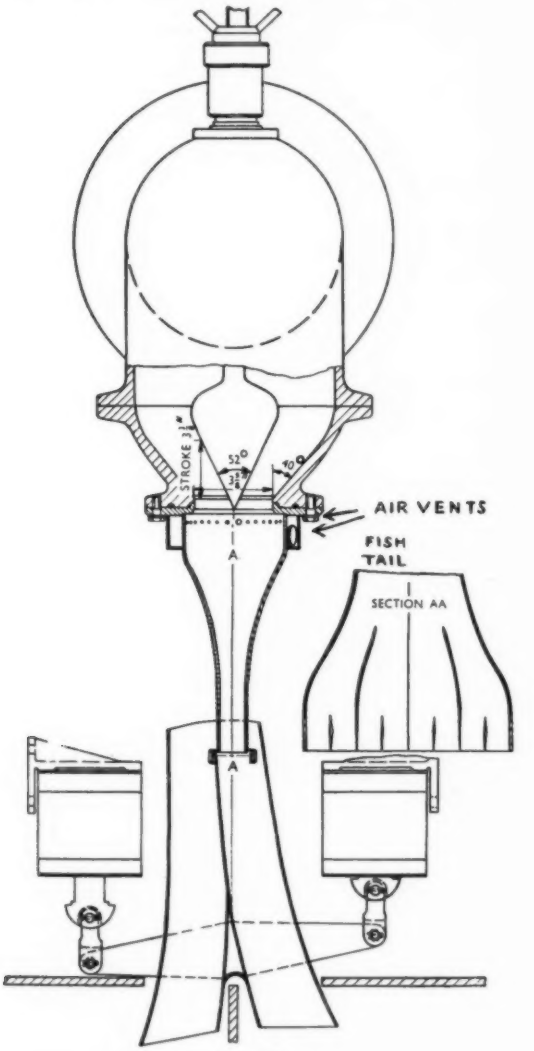
One closed circuit will allow centrifugal or axial-flow pumps, with suction connections up to 20 ft in diameter to be tested. Maximum heads of 600 ft and flow rates up to 8000 gpm—requiring power inputs up to 350 h.p.—are demanded in the closed circuits. The air content of the water may be varied and the absolute static pressure level controlled to give a variety of cavitation conditions. The attention to cavitation is noteworthy, since this phenomenon has a major influence on pump performance.

Before the various hydraulic testing circuits could be assembled, a number of the components had to be specially designed, such as the valves fitted immediately upstream of the flow-diverters; the flow-diverters and the valves discharging to the sumps (Fig. 2). In the closed circuits, special valves were required for producing cavitation conditions on the suction side of the pumps under test (Fig. 3).

For accuracy, the flow-diverting device has to reduce the time taken to direct the flow from the main sump to the measuring tank to a minimum. It also has to be capable of converting the round jet at the valve into a sheet-like jet. Consequently, a number of fish-tail designs were tried out. One difficulty was the unstable flow set up at the point where the nozzle changed from running free to running full. This was overcome by placing a system of air vents immediately downstream of the valve opening (Fig. 4).

For the flow-diverters, valves were required for controlling the flow from 1 to 30 cu. ft/sec. with a linear relation between flow rate and valve travel. The valves have to discharge to atmosphere under a constant head of 48 ft and must provide a clean and symmetrical jet at all flow rates.

The specification for the sump valve is: maximum pressure drop, 600 ft of water; minimum pressure drop, 30 ft; maximum flow, 30 cu. ft/sec.; minimum, 1 cu. ft/sec.; maximum power to be dissipated at any value setting, 350 h.p. This valve had to be designed to avoid violent disturbance of the water surface at the sump without introducing substantial quantities of air. It consists of a perforated piston which moves upwards or downwards within a ported cylinder. The amount of register of port and perforation decides the discharge area. It was found that the best valve was one whose free area was made to vary as the third power of the sleeve movement. A perforated metal screen was fitted around the valve cylinder to prevent disturbances of the sump surface.



b Details.

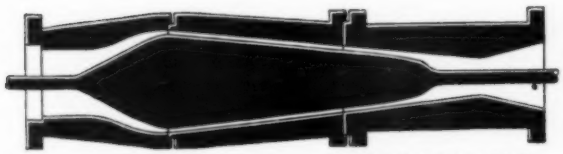


Fig. 4. Special valve for diverting flow to weigh tank. Note system of air vents downstream of valve. Fig. 5 (Below). Type of valve used to minimise cavitation.

The closed-circuit valve must be able to produce the minimum fluctuation of pressure and flow, since it is part of a circuit where the masses and volumes available for damping would be smaller than in the case of the other valves. Moreover, freedom from cavitation over a wide range of working conditions is also essential. The best design is one in which energy is dissipated by friction at solid boundaries. The type finally used is shown in Fig. 5.

The valve has to dissipate 350 h.p. with pressure drops varying from 600 ft and flow rates of from 1 to 20 cu. ft/sec. Pressure has to be broken down in such a way that cavitation is avoided over as wide a range as possible, and pressure loss must be as small as possible. In practice, it was found that two valves in series gave the best results.

Service pump throttle valves have to control flow of from 1 to 15 cu. ft of water/sec. with a maximum pressure drop of 120 ft and the minimum pressure loss possible.

The reason for a valve of special design at the flow-diverter can be readily understood when the behaviour of the usual system of controlling out-flow from a pipe system by means of a gate valve is considered. Occasionally the calibrating system may use a short length of horizontal piping, followed by a bend and a short vertical section, discharging into the sump or measuring tank. The gate valve is usually placed at the end of the horizontal section just before the bend. This kind of system has a number of shortcomings; for example, when the outlet pipe is not running full, pressures below atmospheric are set up at the valve. As a result, large bubbles of air flow up the pipe, causing the reduced pressure at the valve opening to fluctuate. In such circumstances pulsations are created up-stream at the flow-measuring instrument. The flow-diverter valve was therefore designed to eliminate such fluctuations. Another disadvantage with the gate valve lies in the difficulty of adjusting it to give low rates of flow, and the design evolved had to give good control of flow under such conditions.

The Use of Air as a Test Medium

A relatively inexpensive way of testing designs of pumps is to use air instead of water as the working fluid. This method of testing is economical, because the design of pump to be investigated can be incorporated in a model made from wood, sheet metal or fibreglass. The need for a hydraulic circuit therefore becomes unnecessary. One disadvantage is that efficiency estimations are more difficult because the ratio of bearing and gland losses to useful output is higher than when a liquid is pumped. Again, cavitation phenomena cannot be reproduced with air. An investigation of the limitations of the air technique is now under way, and the results from an exhaustive series of tests on a small centrifugal pump using water are being compared with those from a geometrically-similar pump model of twice the size using air as the working fluid. Successful methods of correlating air performance with water performance will mean that pump designers will be able to carry out a considerable amount of preliminary work cheaply and rapidly before final investigations using water or other liquids are carried out. Provided the air velocity in these investigations is kept below 200 ft/sec., it is expected that its compressibility will offer little difficulty in deducing liquid from air performance.

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Chemical and Petroleum Plant Contracts

A BRIEF OUTLINE OF THE CONTRACTORS' VIEWPOINT

by D. J. TOW, B.Sc. (Eng.), Dip. Chem. Eng., A.M.I.Mech.E., A.M.I.Chem.E.

EVERY chemical and petroleum plant contractor in this country offers a slightly different type of contract for a particular project, depending upon his company structure and the services in which his company specialises. There is the firm which consists purely of specialists for design, engineering, procurement and erection supervision, and the company which, in addition to these specialists, has its own fully experienced erection staff and manufacturing workshops.

In this article only these two extreme examples have been considered, but, naturally, the position of any company operating within these limits can be interpolated from the statements that follow. An attempt has been made to explain briefly the four main types of contract most frequently employed by plant contractors to the chemical and petroleum industries and to suggest to the reader suitable terms for the execution of various types of project.

The Main Types of Contract

There are usually five components in any complete contract and the four main types of contract are derived by different considerations of these components. They are as follows: (1) materials; (2) contractor's services; (3) contractor's overheads; (4) contractor's fee; and (5) site labour (see Table I).

Certain of the main types have subdivisions and an explanation of these is given later.

Type A: In this, the contractor agrees to provide the complete plant or sections of the plant for a firm price which shall, however, be subject to escalation due to wage and material cost changes. The contractor specifies closely the service quoted and upon what basic data his offer has been prepared. He has a legitimate claim for extras, should this basis be altered at any time.

Should only certain of the contractor's services be required in each case, the limits of the order will be closely defined and also the basis upon which the contractor's offer was made.

As a variation to this type of agreement, there is the fixed-price contract where prices are not subject to escalation due to rise and fall of material or labour costs. The contractor usually includes a "fixing-contingency" in his price to cover this risk.

Type B: Here the contractor offers to carry out certain design, engineering, procurement and erection or erection supervision work for a firm or a fixed price (the difference between these two prices has already been explained).

For both types of contractor we are considering, the materials would be bought at prices ruling at the date of each order with the approval of the client, and complete reimbursement to the contractor would be made by the client. In the case of the simple specialist contractor, the erection labour is also treated as a material "buy-out". In a slight modification to this scheme the contractor may place orders on behalf of the client, with the sub-contractor's invoices being paid direct. Here, again, the extent of the services offered, the extent of the plant to which they are applied and the basis upon which the offer has been made would be clearly stated and any deviation from these would result in an extra claim by the contractor.

As a variation of this type of contract, the client and contractor may agree on a ceiling figure for the total price of the plant. If the cost is less than this figure, the difference would be shared in some ratio between the contractor and the purchaser and, similarly, if the sum exceeds the ceiling figure another ratio of sharing may be applicable.

Type C: In this case the contractor will, after consideration of the scope of the plant and the services required, fix his fee, and offer his services on the direct cost of the specialist labour involved plus a percentage to cover the company's overheads.

The materials for the project would be charged at cost. The large contracting organisation with its own erection facilities may seek to obtain payment for these services at cost with an overhead which may differ from that stated for their other specialist services. Alternatively, it may, in line with the other type of contractor we are considering, treat the site work as a material "buy-out" and charge this work at cost. This would, naturally, include the erection division overheads and fee.

In an agreement of this nature certain deviations from

Table I. Contract and Contractor

Type of Contract	Type of Contractor	
	Complete Organisation	Specialist Organisation
A	All components at firm price.	All components at firm price.
B	1 at cost. 2–5 firm price.	1 and 5 at cost. 2–4 firm price.
C	1, 2 and 5 at cost. 3 as percentage on 2 and 5. 4 firm price.	1, 2 and 5 at cost. 3 as percentage on 2. 4 firm price.
D	1, 2 and 5 at cost. 3 and 4 as percentage on 2 and 5.	1, 2 and 5 at cost. 3 and 4 as percentage on 2.

the initial scope of the plant can be allowed, as the client is paying "cost-plus" for the extra work involved. Naturally, the contractor must limit these extras, as his fee is fixed and would be correspondingly reduced as a percentage if direct costs are increased by alterations in the scope of the project. Although this is an "open-ended" contract, in a certain sense there is an incentive for the contractor to complete the job economically so that his management fee is as large a percentage as possible of the total cost of his services.

Type D: This form of contract is more readily applicable when the scope of the plant is not well defined in the initial stages and the contractor is unable, therefore, to fix the overall cost of his services or his fee. The direct cost of the contractor's specialist labour involved, plus a fee to cover his overheads and profit, is the basis of the quotation. A ceiling figure is usually fixed which must not be exceeded without recourse to the client. As before, materials would be charged to the client at cost or sub-contractor's invoices paid direct by him.

Choosing the Right Contract

The important question to be decided is which type of contract should be selected, and this depends upon three major factors.

(1) Can sufficient time be given to the contractor for him to prepare his bid?

(2) Can the contractor be paid for preparing a detailed estimate?

(3) Is the full scope of the plant known in the inquiry stage?

Usually, nowadays, negative answers must be given to these three questions; thus some form of cost-plus contract is required. If, however, time can be allowed for a contractor to prepare his quotation and the scope of the plant is fully defined, then the client will usually opt for a firm price contract (*Type A*). It should of course be remembered that present-day conditions are such that the majority of contractors have a large amount of work on their books and, therefore, they may not be prepared to spend the time and the money on producing a firm estimate when the man-power required for such work could be utilised on contracts in hand or on new "cost-plus" contracts.

This raises the second question mentioned above. If the contractor can be paid for preparing the detailed estimate, he will naturally be far more interested in rearranging his work programme to allow for this estimate to be prepared. If the client is not prepared to pay, then the contractor must consider not only his work loading as mentioned above, but also the possibility of his gaining the contract in the end. It may be that the inquiry has been sent to a large number of companies and his chances could therefore be small. This factor must be seriously considered by the contractor having at his disposal all the intelligence information available regarding the project before making a final decision.

If a certain amount of time is available and the scope of the plant reasonably well defined, then it may be possible for the contractor to quote according to contract *Type B*. In this case he does not have to estimate accurately the cost of the materials and site labour required and the time required to prepare a quotation is therefore considerably shorter.

Contract *Type C* is usually considered if there is little time available before work on the order must start and the scope of the plant is only roughly defined. The contractor's services can then be increased or reduced in accordance with the final scope of the plant, and yet the profit accruing to the contractor is fixed in the initial stage.

Finally, if the scope of the plant is not even roughly defined, and/or there is no time to prepare any costs, then the fourth type of contract (*Type D*) is the only one that can be considered.

In the conditions that prevail today most contractors in this country are offering, and having accepted, quotations of the third or fourth types.

Naturally, claims made under contracts of these two types (*C* and *D*) for the services given by the contractor are checked against certified statements of time worked on each contract. This flexible type of contract has been proved to have many advantages where clients wish the plant to incorporate every last-minute development and design feature.

Selecting the Right Contractor

It will be appreciated from the above that competitive quotations of *Types A* and *B* are seldom obtained under present-day conditions, and it is difficult to compare quotations based on *Types C* and *D*. Hence, contractors are selected mainly on the basis of their reputation and their experience of the type of plant being considered. The size of a contractor's firm is also an important factor. A small company may have the means to expand rapidly in order to handle a large contract, but such an arrangement would most likely be uneconomical. Similarly, it may not be economical to give a small job to a large organisation as the overheads of this type of company may be prohibitive.

The financial backing of the contractor must also be considered to ensure that responsibilities assumed at the commencement of work can be fulfilled in the event of any mistakes arising in the services offered. Finally, of course, the load factor of the contractor should be investigated to make certain that promises with regard to delivery, etc., can be maintained. Thus the contractor should be chosen on the basis of past experience, integrity, financial soundness and responsibility, and, of course, availability.

KELLOGG'S EXPANSION

KELLOGG INTERNATIONAL CORPORATION has been represented in the United Kingdom since the early 1920s. It has maintained a London office, firstly in Bush House, Aldwych, and then in Bishopsgate. In 1952 it moved to Kellogg House, Chandos Street, W.1., and since that date it has expanded the premises and doubled the floor space, which now amounts to over 46,000 square feet. This physical expansion is a reflection of the company's policy of developing and strengthening its London staff so that it can assume ever-increasing responsibilities for performing the services of engineer-contractors for the oil-refining and chemical industries in Britain and continental Europe, in the sterling area and in the Middle East.

The major projects organised by Kellogg from London include the following: three cat crackers for B.P. in Britain; a complete oil refinery for B.P. at Kwinana in Australia, and another for the Government Oil Refineries Administration in Baghdad; a large cat-reforming unit for Raffinerie Belge de Petroles in Antwerp; and a large cat-cracking and polymerisation unit for Compagnie Française de Raffinage at Le Havre. For British Hydrocarbon Chemicals, Kellogg put up a butadiene extraction unit at Grangemouth. The company has built a couple of olefin-cracking units for I.C.I. at Wilton. A start has been made on the design of a third unit, which will contain novel features including the use of free-piston gas generators.

Nomograph for Density of Dilute Aqueous Phosphoric Acids

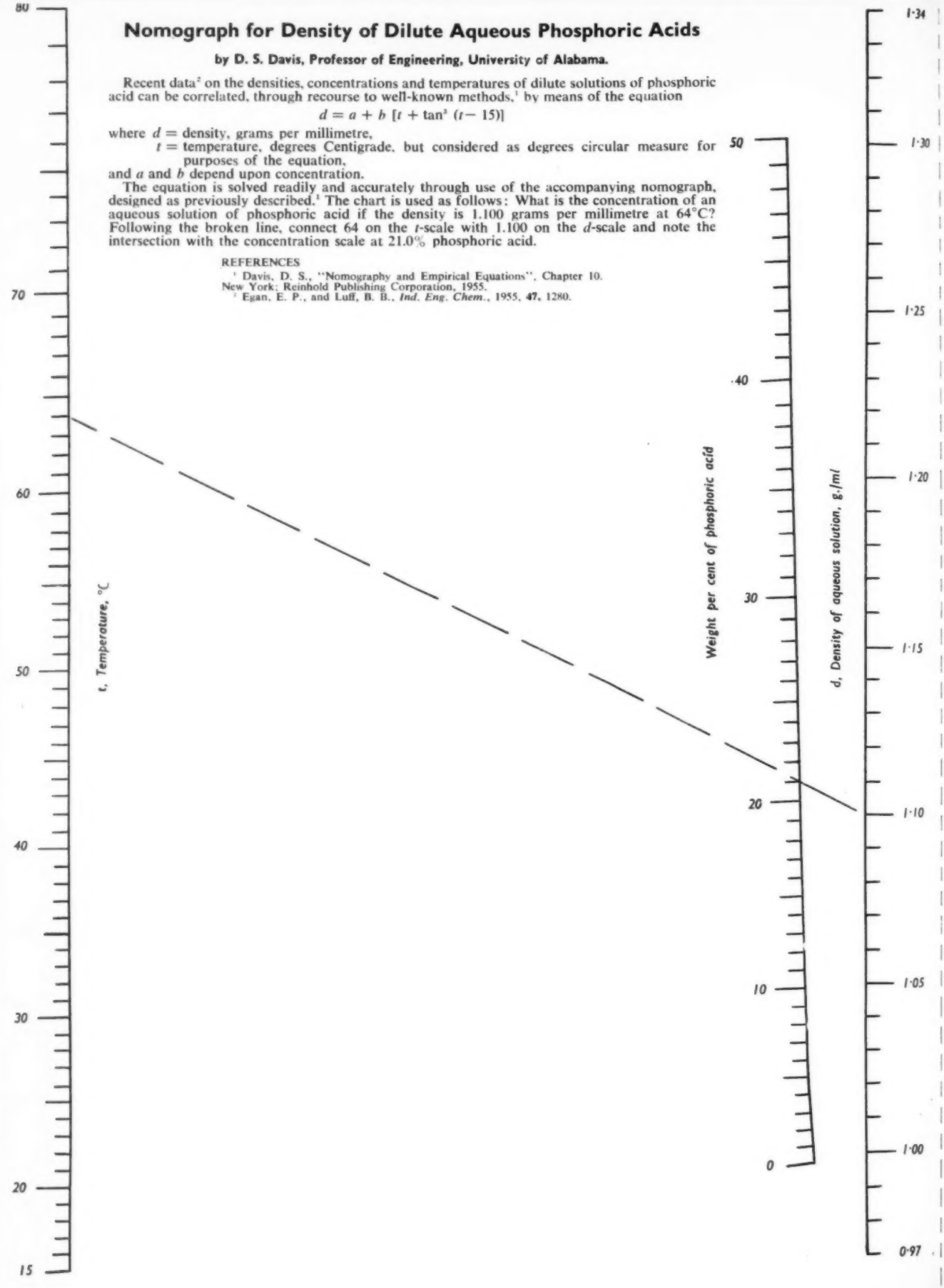
by D. S. Davis, Professor of Engineering, University of Alabama.

Recent data[2] on the densities, concentrations and temperatures of dilute solutions of phosphoric acid can be correlated, through recourse to well-known methods,[1] by means of the equation

$$d = a + b\,[t + \tan^3 (t - 15)]$$

where d = density, grams per millimetre,
t = temperature, degrees Centigrade, but considered as degrees circular measure for purposes of the equation,
and a and b depend upon concentration.

The equation is solved readily and accurately through use of the accompanying nomograph, designed as previously described.[1] The chart is used as follows: What is the concentration of an aqueous solution of phosphoric acid if the density is 1.100 grams per millimetre at 64°C? Following the broken line, connect 64 on the t-scale with 1.100 on the d-scale and note the intersection with the concentration scale at 21.0% phosphoric acid.



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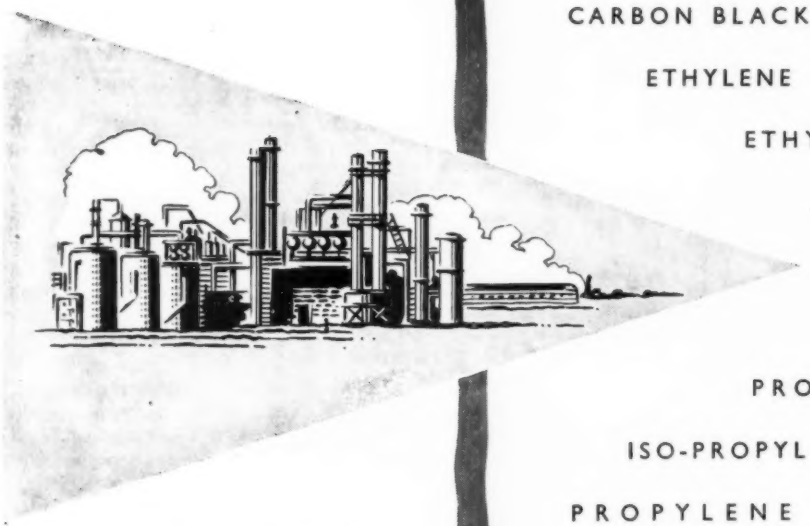
Chemicals and Petrochemicals



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AMERICAN LETTER

The Annual Power Show

THE annual Power Show held in New York towards the end of 1956 included over 300 exhibitors engaged in the steam-raising, power generation and process industry fields. The equipment shown covered a wide range, from steam traps and packings, to large package-type boilers, economisers and pumps. Of particular interest was the emphasis given to power from atomic energy. About ten organisations displayed models of reactor steam-generators they were offering to industry, and the physics department of New York University even demonstrated a working sub-critical reactor operating in a vessel which once must have been an oil drum. This, however, was not intended to be America's answer to Calder Hall.

The manufacture of package boilers is now a fine art, even in a country where fuel shortages are unheard of. Eleven firms exhibited units, ranging in all from 15 to 600 h.p., at pressures from 10 to 250 psi. The Cleaver-Brooks Co. have developed "go anywhere" units mounted on pneumatic tyres; the smallest is rated at 50 h.p. and the largest at 125 h.p. The Vapour Heating Co. offered one of the most compact power packages so far seen—a 100-h.p. unit operating at 250 psi which occupied a floor area of only 5 ft by 7 ft 3 in. Several firms have adopted the "spinning gas" technique to attain high heat-transfer rates and maximum thermal efficiencies. This principle involves the propulsion of combustion air and gases at high velocities in a spiral manner through the boiler tubes, and, in some cases, only two passes are required for maximum thermal efficiency. Electrode boilers were also seen. Pantex showed this type of steam generator in sizes from 2 to 40 h.p., and for pressures up to 500 psi, with efficiencies of 98%. These units represent a convenient way of raising steam in moderate amounts on the spot, and with fully automatic control if required.

Power Reactor

As regards power reactors, probably Atomics International Inc. offered the greatest range. The smallest was a solution-type research reactor of 50 kW, followed in size by a pool-type rated from 100 kW to 1000 kW, and a tank-type using enriched uranium and moderated by graphite, with an output of 1000 kW. A sodium-cooled power reactor of 100 mW was also offered to industry for large-scale purposes.

The estimated total operating and maintenance costs were said to be 9 mills per kWh for a thorium-type reactor. In future models the cost would be reduced to 6.5 mills per kWh. Total capital costs were said to be $265 per kW, but would be about $200 in future installations also using thorium. The Nuclear Development Corp. of America are building a sodium-deuterium reactor for supplying electricity to Anchorage, Alaska. Estimated completion will be in 1962 and the plant will have an output of 10,000 kW net. The estimated cost of electricity will be 12 to 18 mills per kWh. An unpressurised reactor vessel will be used and steam at 850 psia will be produced. In remote areas, this company claims to compete with any power costs of the order of 10 mills per kWh or more. The American Turbine Corp. gave details of a small Escher-Wyss type of gas-cycle reactor-driven steam turbine set of 5 mW capacity, which is available to industry. A helium-to-air heat exchanger is used. A delivery date of 18 months is quoted for the 5 mW size and two years for units of 10 to 15 mW capacity. A marine power unit rated at 20,000 shp, using nitrogen as the working fluid, is also available. Thus, it is only a matter of time before power reactors for industry and transport become commonplace. Currently planned projects will yield one million kW by 1962 in U.S.A.

A complete section of the Power Show was devoted to rocket and missile engineering. Although this appeared incongruous at first sight, the reason gradually became apparent. The display was another determined attempt to induce engineers of many types to work on vast missile schemes in sunny California. The development of super-power rocket units using solid and liquid propellents poses unique problems in chemical engineering and metallurgy, as well as aerodynamics. It is possible that such power units operating under restrained conditions might have certain applications to industries where packaged power is needed. One adaptation of a rocket-type power unit to oil field technology was described and, no doubt, other uses will eventually be found. Power packages can be supplied ranging from match-box size to enormous containers about 20 ft. long. A typical example is the unit developed by Reaction Motors Inc., which weighs only 225 lb. yet generates 250,000 h.p.

Chemical Engineering Plant

A number of exhibits were of direct interest to chemical engineers. Some of the equipment shown was readily available in Britain and Europe, so need not be reviewed. However, a brief mention will be made of items of probable interest. A wide range of butterfly valves was displayed by the Keystone Corp. from 1 in. to 48 in. diameter. These valves are flangeless, yet can be simply mounted between standard pipe flanges and can operate on liquid pressures up to 150 psi, or can be used to maintain a good vacuum. They have excellent loss characteristics and are suitable for use with a wide range of slurries, liquids and gases. An uncommon feature in the valve field was the reconditioning service offered by the Nutype Valve Servicing Corp. of New York, which covers servicing and exchange for all sizes and types of valve up to 48 in. diameter. Yarnall-Waring showed a large selection of improved, packed expansion joints. Sarco Inc. had a new type of steam trap on display. This TD model is only a cubic inch or so in size and contains only one moving part—a steel disc—and is suitable for pressures from 10 to 600 psi. Biach Industries Inc. demonstrated a hydraulic filter-press closer, adaptable to any mechanically operated plate and frame press. They also showed a hydraulic bolt tensioner which simultaneously tensions up to 30,000 psi any number of flange- or rim-bolts without inducing torque. This device can also be used for loosening bolts.

Johnson-March Inc. demonstrated their latest hydro-precipitator scrubber, which has an efficiency of 99.8% on dust loadings of 5 grains per cu. ft, where 70% is below a size of 5 microns. These units are available in capacities from 500 to 60,000 cfm, and use very little scrubbing water. The Green Economiser Co. of New York showed several types of dust collector. Among them was the Aerodyne filter cone collector and the fully-automatic Sure Seal collector, which incorporates a disposable roll of filter medium and is suitable for flows from 6,000 to 187,200 cfm at velocities of 500 fpm.

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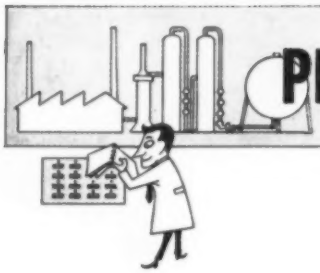
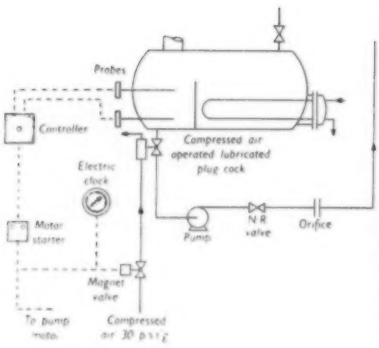


PROCESS ENGINEER'S NOTEBOOK

Electric Clock for Flow Totalling

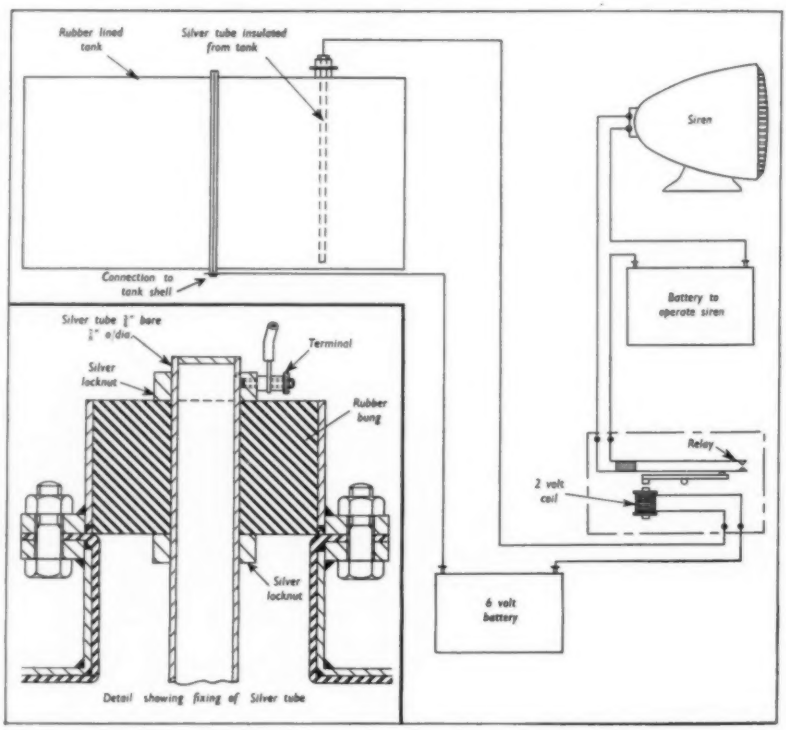


AN INEXPENSIVE METHOD of arriving at the total quantity of fluid pumped from a vessel fitted with a twin-electrode type of level controller is one based upon the product of time and rate of flow—provided that the latter can be maintained constant. In the system illustrated, the main components are an electrical clock and a calibrated orifice; the former works in conjunction with the pump motor-starter which is operated by the level controller. Hence the clock runs only when the pump is running. The orifice is fitted in the pump discharge line.

When the pump is shut-down the pressure conditions in the vessel may require it to be isolated from the pump, in which case it is advisable to fit an air-operated plug-cock at its base. The air supply to this cock is controlled by a small magnetic valve whose action is also controlled by the level controller. In cases where the processing vessel is under a pressure high enough to make a pump unnecessary for transfer of the contents, the arrangement becomes simpler. For low rates of flow the cock may be replaced by a magnetic valve.

An Alarm for Lined Vessels

THE PROTECTIVE LININGS of vessels containing corrosive liquids can usually be relied upon to give long service. It is worth while, however, to have an alarm installed with such a vessel which will indicate when the lining has suffered perforation. One such device, shown in the diagram, is in use at the B.D.H. Works, Poole. This particular installation is one where hydrochloric acid solution is stored in a mild-steel, rubber-lined tank. However, the method is applicable to any lined vessel used for storing an electrolyte, provided that the lining material is a non-conductor of electricity, such as glass, P.V.C. or a synthetic finish (e.g., "Lithcote"). The materials to be stored may require an electrode material, other than silver, as shown in the diagram. For example, if phosphorus oxychloride is being stored in a glass-lined vessel, a nickel electrode could be used. A valuable feature of this system is that the alarm signal is given at the very onset of lining failure; thus the damaged lining can receive attention before the main body of the vessel is seriously corroded.



Plug Cock Lubrication Simplified

THE FOLLOWING is a brief account of the measures taken at the I.C.I. Billingham factory to standardise plug cock lubricants and to facilitate plug cock lubrication. First the engineers decided to use lubricants from one supplier only. The next stage was to settle upon one lubricant for all duties, and a general-purpose lubricant was selected which met the requirements of the majority of applications. There were, however, a sufficient number of applications to merit the inclusion of an alternative lubricant. These were:

(1) General applications where contamination of the process liquor with the dark component of the general-purpose lubricant was objectionable: a colourless variety was accepted.

(2) When nitrating acids were the process liquor.

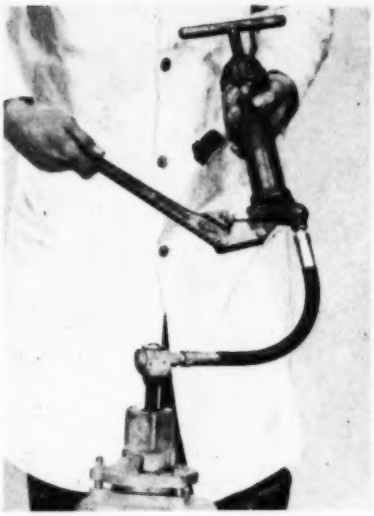
(3) When the valves had to handle petroleum fluids.

(4) When high-pressure water or steam were the process liquor.

With the exception of No. (2), where there is chemical attack of the lubricant, the general-purpose lubricant can be used for the abnormal applications [(1), (3) and (4)], provided the cocks are in good condition and free from wear and if over-lubrication is avoided.

The alternative lubricants are included to deal with cases of cocks which have deteriorated sufficiently to perform unsatisfactorily with the main standard lubricant.

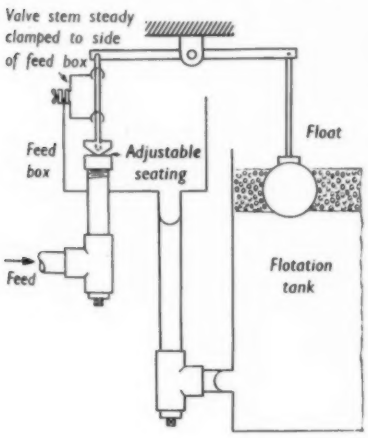
The method of stocking the lubricant and dispensing it had next to be considered. The normal method of lubricating a plug-cock is to insert a stick of lubricant into the top of the cock and force it to the moving parts of the cock by means of a screw. This method ensures lubrication, but it means the storage of many different-sized sticks of lubricant. Fitting a grease nipple to the cock and pumping grease into it is a successful method of overcoming the stick problem (see photograph). A special adaptor is now



used which incorporates the grease nipple and the lubricant screw in one piece. This permits filling of the grease space by means of a grease gun and subsequent attention to the cock with a spanner until the grease supply is exhausted. Thus the filling of cocks with grease can now be done by a maintenance greaser and the regular attention of the cock by the process operator.

Simple Level Controller

THE ILLUSTRATION SHOWS a simple method of controlling the level of pulp in a pilot-plant flotation tank. The main components are a small feed tank, which discharges to the base of the flotation vessel, and a float-operated valve. The valve float is situated in the flotation tank, whereas the valve proper is fitted in the small feed tank. The valve plug and seating are slightly conical in shape and are ground together to give a good seal when the valve has to be closed. The valve seating can be conveniently made from a standard screwed socket, and has the advantage of ready adjustment and renewal. The plug is suspended by a rod from the pivoted arm carrying the float, and a simple guide, made from stout wire clamped to the side of the feed tank, is provided to ensure that the plug sits properly upon its seating.



Catalyst Regeneration

MANY CATALYSTS ARE regenerated by burning the carbon deposited on their surfaces with air. Admission of air to the catalyst regeneration vessel must be carefully controlled to avoid the generation of excessive temperatures at the catalyst surface, which would otherwise destroy its activity. The speed of the combustion reaction requires an instrument with a very rapid response. One such instrument is the infra-red analyser. Taking advantage of the fact that carbon monoxide in the regenerator gases is a sign of excessive temperature, the infra-red analyser instantaneously detects traces of the monoxide, and thereby acts as an excellent temperature indicator for the control of the catalyst regeneration process.

Sludge Filtration in Acetylene Manufacture

A FIRM CONCERNED with the manufacture of various gases uses filter presses clothed with nylon to dewater the sludge which remains after the production of acetylene. The sludge, almost pure hydrated lime, has a moisture content of 80 to 85%. This is reduced to a cake with a water content of about 45 to 50%. The sludge is filtered at a temperature of about 80° to 100°F at a pressure which reaches 80 lb./sq. in. The presses operate on a one-hour cycle. Under these conditions, cotton twill was found to have a life of about a fortnight. Trials with 12-oz. continuous filament nylon cloths showed that some of them lasted more than a year and that their average life was 20 times greater than cotton. Allowing for the greater initial cost of nylon, this means a saving of 75% of the annual expenditure on cloth. Recent work with a different type of nylon cloth, consisting of a mixture of continuous filament nylon and staple nylon and weighing about 10 oz./sq. yd., indicates that the results are even more satisfactory.

AN AUTOMATIC PROPORTIONING SYSTEM

MANY mixtures produced in factories are quite complex, and formulæ involving as many as eighteen ingredients are not uncommon. A good example is the mixing of various kinds of provender. Modern nutritional knowledge has led to the development of formulæ for balanced feeding stuffs which include nearly twenty different ingredients. The weighing of these ingredients needs to be carried out as *rapidly* and *accurately* as possible, and the latter point is particularly pertinent whenever expensive ingredients (e.g., vitamin preparations) are involved. The same considerations arise in a large variety of industries; thus the rubber industry is concerned with the proper proportioning of rubber additives, and the same sort of problem arises in the preparation of compound fertilisers and the formulation of cement products.

The Select-O-Weigh system represents a major advance in the automatic weight-proportioning field. This was originated by the Richardson Scale Company of Clifton, New Jersey. Henry Simon Ltd. and Simon Handling Engineers Ltd., of Cheadle Heath, Stockport, now manufacture this equipment. These two associated companies did extensive research and development before releasing it.

Punched Cards

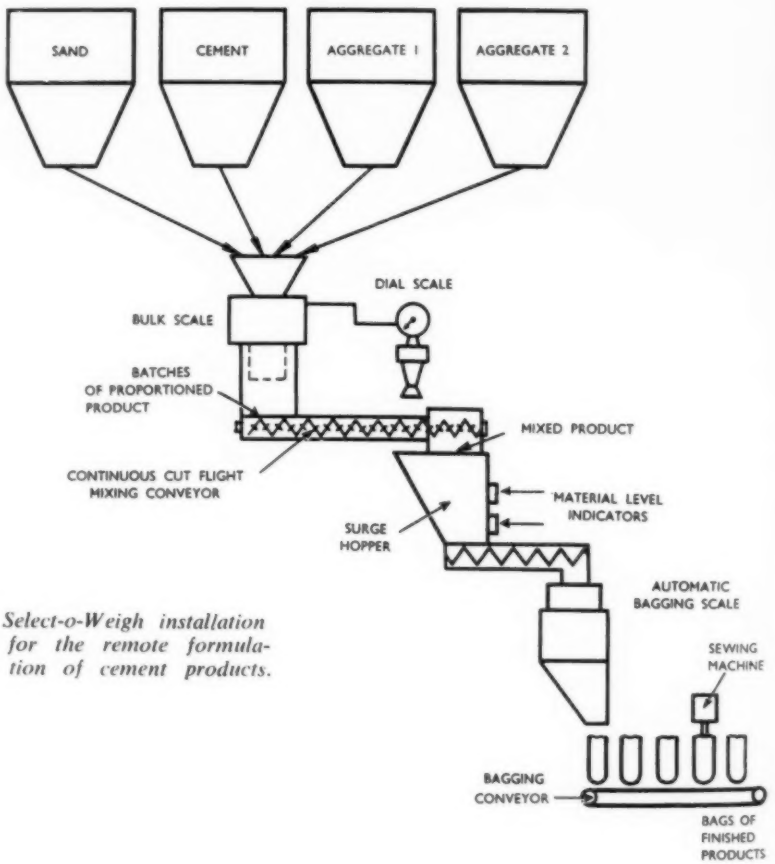
An extra refinement has been worked out by this development team, in conjunction with Powers-Samas, which makes it possible to use punched cards for programming the whole of the sequence of weight-proportioning operations.

The principle of Select-o-Weigh can be understood from the example (which does not involve the use of punched cards) illustrated by the accompanying diagram. The ingredients required for making one particular batch of the mixture are weighed out one after the other. The sequence of weighing operations is controlled by a central control panel; the selector dials on the panel are set and then the succession of weighings begins, the correct quantity of each ingredient in turn being delivered to the mixing apparatus. Only one weigher is required in this particular example; with a more complicated mix—e.g., a provender mix involving eighteen ingredients—two weighers may be needed, each, successively, handling nine ingredients.

When the formula of the mixture needs to be varied from batch to batch the additional refinement of punched-card control becomes extremely valuable. The various formulæ are punched on the cards. When a particular card is fed into the card reader coupled to the control panel, it automatically adjusts the system so that it will deliver the correct amounts of the various ingredients. This procedure is repeated, card by card, to give a succession of accurately proportioned batches.

The statistics for each successive set of weighing operations can be recorded by means of an automatic typewriter. Alternatively, these data can be recorded on punched cards which can then be put through a data-processing machine to provide all the figures required for stock control and other accounting purposes. To a card which records the weight of a particular ingredient in a particular batch can be added a hole corresponding to the current price per pound of the material. Such a card can be processed by a calculator (e.g., the "Emp" electronic calculator) which multiplies quantity by price and punches the answer into each card; "Emp" can do this job at the rate of 7200 calculations per hour. Such detail cards can be merged with the previous day's balance cards and today's receipt cards, and are then ready for tabulation. The tabulator machine prints a detailed record of materials held and used, showing date, formula number, description of each material, quantity received or weighed out, price per pound and price per weighment.

Already a number of Select-o-Weigh equipments have been sold in Britain and abroad, including Canada and the U.S.A. In all cases the individual equipment has been "tailor-made" to meet the special requirements of the customer. It needs to be appreciated, however, that the Select-o-Weigh system is extremely flexible, even though it is necessary at the present time to design each Select-o-Weigh installation individually and to build it to suit a specific project.



Select-o-Weigh installation for the remote formulation of cement products.

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Book Reviews

Air Pollution Handbook

Edited by P. L. Magill, F. R. Holden and C. Ackley

McGraw-Hill Book Co., New York and London, 1956, 112s. 6d.

THE "smog" disaster of 1952, which killed several thousand Londoners, exceeded the limits of air pollution which the public was prepared to tolerate. The Clean Air Act was the direct result of the public outcry which resulted from that appalling incident, which was so serious that it can be compared with only two other similar disasters—the exceptional pollution of the Meuse Valley of Belgium in 1930 and of Donora, Pasadena, in 1948.

Public opinion in many countries is now thoroughly aroused to the evil of atmospheric pollution, and technical opinion is now bound to follow suit. This handbook, which is edited by three men of the Stanford Research Institute with the advice of F. G. Sawyer of the Ralph M. Parsons Company, is an extremely topical and useful compendium that summarises all the essential data on this important subject. Atmospheric pollution is an involved subject, which concerns many different experts—chemists, engineers, meteorologists, plant physiologists and others. Moreover, the pertinent literature is widely scattered. It is not surprising, therefore, that the editors of this handbook found it necessary to recruit the services of some thirty authors to cover the various aspects of atmospheric pollution.

No one is likely to remain unappreciative of the severity of atmospheric pollution in industrial countries after reading this work. After realising that the total amount of sulphur that pollutes the atmosphere of North America exceeds the total production of native sulphur, no reader is liable ever again to underestimate the seriousness of this type of problem. Sulphur dioxide is, of course, one of the major pollutants. A concentration in excess of 0.5 ppm by volume can injure the leaves of many plants. Very high levels of sulphur dioxide concentration have been reached in the vicinity of industrial plants such as the lead-zinc smelter at Trail, British Columbia, which used to pour out 600-650 tons of sulphur dioxide per day, as against a daily output of metal amounting to approximately 1000 tons. The damage done by this plant cost a mint of money; for instance, the commission which investigated the damage done up to the end of 1931 assessed that it was equivalent to $350,000. In that year sulphur-recovery units were brought into operation, and by 1940 sulphur emission had been reduced to as little as one-third of the 1930 maximum. This Canadian case illustrates what can be achieved when industrialists decide to deploy to the full what the scientific experts and technologists know about the minimisation of atmospheric pollution.

The most serious pollutants are discussed in the chapter headed "Chemistry of Contaminated Atmospheres" by R. D. Cadle and P. L. Magill. This effectively establishes the scale on which pollution occurs; for example, a power station burning 5000 tons of coal per day can discharge as much as 500 tons of sulphur dioxide, while the automobile exhausts of a city like Los Angeles account for no less than 700-1000 tons of volatile hydrocarbons, some of which are almost certainly seriously carcinogenic. Oxides of nitrogen are important too; in U.S. cities concentrations of up to 0.8 ppm have been recorded. Fluorine produced by plants producing aluminium, steel and phosphate fertilisers has also caused a great deal of trouble.

Weather effects have occupied the attention of many first-rate workers, and the book contains an excellent chapter on the evaluation of these factors by C. A. Gosline, L. L. Falk and E. N. Helmers (who are all associated with E. I. du Pont). This chapter is particularly valuable for the review it provides of all the key work done on the dispersal of smoke from chimney stacks, a subject which Sir Graham Sutton discussed recently in *British Chemical Engineering* (August, 1956, pp. 202-205). We note with interest that these American experts have exploited to the fullest extent the brilliant work done by Sutton, and one cannot help thinking that the American's have a better appreciation of the importance of Sutton's ideas than his own countrymen; probably this chapter will serve the useful purpose of ensuring that he is recognised as a prophet even in Britain!

The pollution damage to farm crops and stock is well treated in two separate chapters. Arsenic, fluorine and lead have proved the most serious poisons so far as farm animals are concerned, and most of the relevant chapter is devoted to the trouble these elements cause. A considerable amount of work has been done on the effects of air pollution on plants (129 references are listed on this subject), but it is quite obvious that more research in this field ought to be sponsored in Britain; the one and only recent English research we know was that done at Manchester University in Prof. S. C. Harland's department, and that was only a very minor investigation. The Agricultural Research Council would be well advised to allocate some money so that this line of research can be properly developed in Britain.

Two useful chapters on Sampling Procedures and Analytical Procedures are followed by Leslie Silverman's invaluable survey of experimental test methods.

The remainder of the volume is devoted to equipment and processes available for the abatement of air pollution. This contains the kind of data—on such aspects of the subject as dispersal of smoke from stacks, combustion theory and calculations, collection of aerosols and control of gaseous pollutants—which chemical engineers who have to tackle these problems will find indispensable.

The editors of this volume, which is beautifuly produced and most effectively illustrated, deserve to be congratulated for producing a first-class handbook. It certainly deserves to become a "best seller" on both sides of the Atlantic, because of the immense topicality of the subject-matter and because of the comprehensiveness which the editors and the contributors have attempted and achieved.

The Condensed Chemical Dictionary

by Arthur and Elizabeth Rose

Reinhold Publishing Corporation, New York; Chapman & Hall Ltd., London; 1956, 110s.

THIS latest edition of a dictionary which many readers will find extremely useful contains over 30,000 entries. Its up-to-dateness may be judged from the fact that it includes entries for the Ziegler polythene process, though some of the relevant trade names (e.g., "Marlex") have not yet got in. There is naturally a strong American bias; this is revealed by the absence of such important British trade names as "Alkathene". Incidentally, one notes with interest this statement referring to *polythene*: "The word is no longer current in the United States, but is still used in England." This must be one of the rare occasions when the most convenient generic name—polythene—has been dropped in favour of the longer word (polyethylene). It is unusual for Americans to be more pedantic than the British; but probably any comment on this point is a waste of time in an age when, in the realm of etymology, "anything goes" is the general rule.

BCE 765 for further information

Chemical Engineering In the Coal Industry

Edited by Dr. F. W. SHARPLY

contents

Controlled Oxidation of Coal
by A. F. BOYER, Groupe Carbonisation, C.E.R.Ch.A.R., France.

Fluidised Oxidation of Coal
by Dr. G. I. JENKINS, B.A., B.Sc., D.Phil., Head, Carbonisation Department, Coal Research Establishment, National Coal Board.

Investigations into the Carbonisation of Briquettes in Germany
by Dr. Ing. W. REERINK, M.Inst.F., Steinkohlenbergbauverein, Essen, Germany.

Hot Briquetting
by D. H. GREGORY, A.M.I.Chem.E., A.M.Inst.F. Head, Briquetting Department, Coal Research Establishment, National Coal Board.

A Study of Semi-Carbonisation in a Fluid Bed
by A. PEYTAVY, Sections d'études générales, C.E.R.Ch.A.R., and P. FOCH, Chef du service, Station experimentale de Marienau, C.E.R.Ch.A.R., France.

The Study of Tars Obtained in Fluidised Carbonisation
by Dr. G. H. WATSON, Ph.D., D.I.C., Head, and Mr. A. F. WILLIAMS, M.Sc., A.M.Inst.F., By-Products Department, Coal Research Establishment, National Coal Board.

Industrial Treatment of Low-Temperature Carbonisation Tars
by J. L. SABATIER, Directeur General des services économiques, Houillères du Bassin de Lorraine, Chapbonnages de France, Merlebach, France.

Review of the Conference
by Dr. J. Bronowski, M.A., Ph.D., Director, Coal Research Establishment, National Coal Board.

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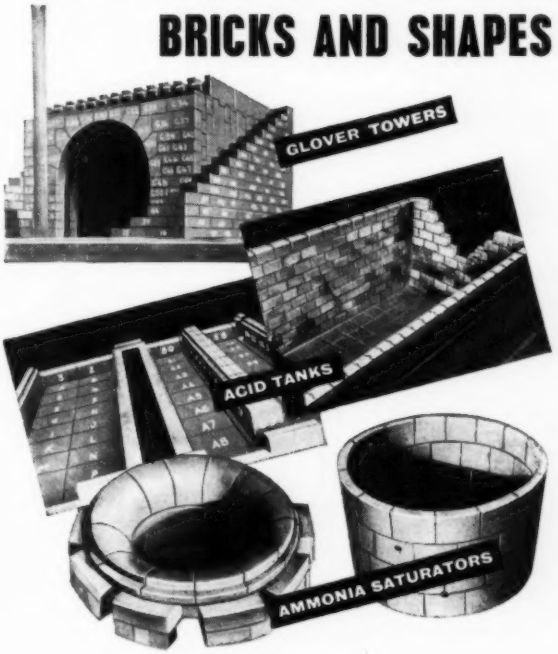

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PLANT EQUIPMENT NEWS

High-temperature-resisting Coatings

The Rokite coating process for protecting metals and other surfaces against extremes of temperature is being made generally available to industry by Norton Grinding Wheels. The process was elaborated by the American parent company, Norton Co., during research into possible new materials for use in high-temperature processes, notably those connected with rocket propulsion. Three refractory substances—alumina, zirconia and zircon—are used, and the process is carried out on the cold article. It has been found that an oxide such as zirconia with a melting point of *c.* 2500°C can be applied to metals having a much

lower melting point, such as aluminium and magnesium. The temperature reached by the article during coating, it is claimed, is unlikely to affect it detrimentally. Certain synthetic resins have been processed without visible charring. The thickness of coat can be controlled closely, and, if necessary, can be varied from one part of an article to another. Construction materials that have been treated satisfactorily include carbon, glass, ceramics and asbestos compositions. The only limitations so far experienced are those of size, and it is not practicable at present to coat the inside of tubes or of holes of less than 3 in. diameter, if the length exceeds four times the diameter. The coating operation can be undertaken by an unskilled operator and involves the use of a pistol-type oxy-acetylene-flame spray-gun. The coating materials are supplied in rod form. **Norton Grinding Wheel Co. Ltd., Welwyn Garden City, Herts.**

BCE 818 for further information

Honeycomb Construction Matrix

Hexmetal is a fabrication of steel-walled honeycomb cells which is designed to be loaded with refractory or abrasive-resistant fillers. When the filler is refractory material the fabrication can be used for linings required to be resistant to temperature variation, abrasion, vibration and corrosion. The honeycomb is constructed with independent pin joints, which, it is claimed, give flexibility to the structure. The pins are not stressed, and are less prone to corrosion, the makers say, than integral lugs. Also, the honeycomb mesh can be employed for the construction of floors that will be subject to heavy impact load. For this purpose a filler of high-grade concrete, 1 to 1¼ in. thick, is recommended, for use on a foundation of inferior mix. The honeycomb, the makers say, acts as a binder and separator, absorbs impact load and vibrations, and inhibits cracking caused by corrosive spillages. **Causeway Reinforcement Ltd, 66 Victoria Street, London, S.W.1.**

BCE 819 for further information

Paints for Wet Surfaces

Dixon's are subjecting certain of their paints to a process developed in their laboratories that enables the paint to unite to damp surfaces when applied by brush. The treated paint, it is claimed, strikes deeply into the pores of the coated surface, in spite of the presence of water. The products are labelled "hydro treated". **Dixon's Paints Ltd., Albion Wharf, Bow, London, E.3.**

BCE 820 for further information

Bin Vibrator

The "30-98" bin vibrator has been designed to provide independently variable amplitude and speed of vibration. The machine incorporates a fractional-h.p. three-phase motor fitted with a variable-speed pulley and adjustment mechanism that drives an out-of-balance weight assembly. The assembly runs in double-row, self-aligning ball bearings housed in cast aluminium. The machine is mounted on a base-plate suitable for attachment to the flat sides of the hoppers or chutes. The variable-speed pulley gives a range of speed of about 2 : 1, and, by changing the size of the driven pulley, any speed between 500 and 5000 revolutions per minute may be obtained. **The 30-98 Co. Ltd., Gatwick House, Lowfield Heath, Sussex.**

BCE 821 for further information

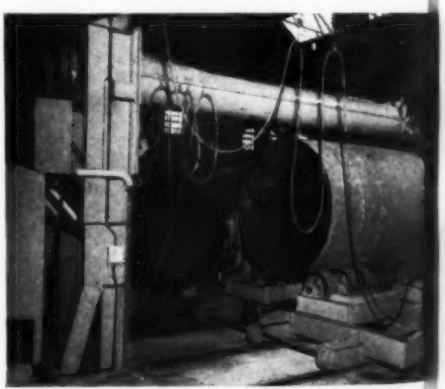
Plastic Coating of Metals

The plant installed by the Schori Division of F. W. Berk, in London, for coating metal parts with plastics such as nylon and polythene has been designed to deal with articles of any shape by spraying and dipping techniques, and it is claimed to be the most modern of its kind in the world. Coating with nylon *R* is of specially wide application as the protection layer withstands temperatures up to 180°C. The coating has a ceramic-like glaze and, Schori say, is free from pores. Other advantages claimed are that the coat is insoluble in oils and in most solvents, including hot trichlorethylene; is unaffected by boiling water, by boiling solutions of salts or by cold acids and alkalis; is not attacked by moulds of bacteria, and it has a compressibility of 8 tons per sq. in. The coating has been used with success in pumps for oil refineries, and its abrasion-resisting qualities have been utilised in pumping unfiltered water. As the coating is flavourless and odourless, it has wide potentialities in the production of foodstuffs, especially in the prevention of ferrous contamination. A wide use for the coating is in the protection of mild-steel heating coils in oil tankers. These coils have a surface temperature of 120°—130°C when in service, but are subject to rapid corrosion when the tankers are travelling in sea-water ballast. In addition to providing the coating service, the company supplies spray guns and other equipment for carrying out the process. **F. W. Berk & Co. Ltd., Brent Crescent, North Circular Road, London, N.W.10.**

BCE 822 for further information

New Boom-welder

The new Unionmelt high-lift boom-welder by Quasi-Arc has been designed to weld internal and external longitudinal and circumferential seams. It comprises an automatic welding head and control panel embodied within a boom 17 ft 6 in. in length. The boom is supported at one end by a mechanically-operated carriage, and its height is adjusted by the use of push buttons on the panel. A lay trough, in which the operator can lie to weld the

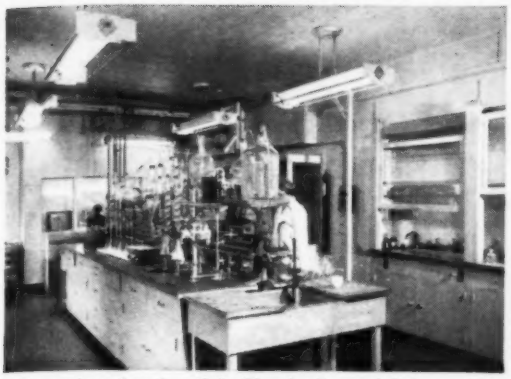


internal seams of small-diameter vessels, is provided on the boom, and the trough can be adapted to provide normal seating when larger vessels are being welded. **Quasi-Arc Ltd., Bilston, Staffordshire.**

BCE 823 for further information

Floating Bin Cover

A new type of floating plastic blanket for eliminating losses from oil storage tanks due to evaporation has been designed by an employee of a company associated with British Petroleum—Société Française des Petroles B.P. It is being manufactured by La Roche Frères. With the support of small floats on the underside, the blanket, which is



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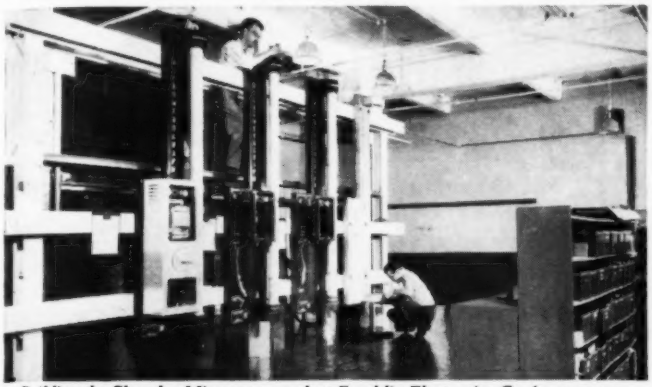
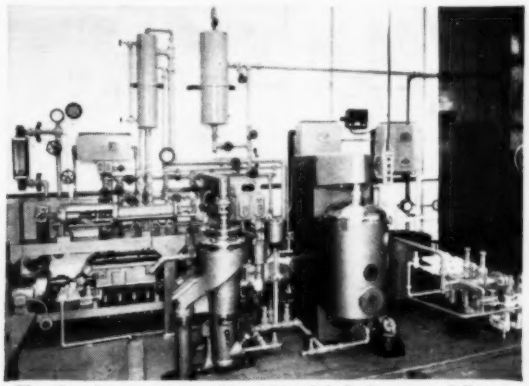
The Lightpill factory producing Sharples equipment. Additional Sharples manufacturing plant and full scale laboratories are currently being built at Camberley, Surrey.



Building the Sharples Micromerograph at Franklin Electronics Co. (a company of the Sharples group). This instrument, for continuous automatic measurement of particle size, is a recent development by Sharples.



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PLANT EQUIPMENT NEWS

made of polyvinyl chloride sheet, floats on the surface of the oil. To prevent vapours escaping at the edge, a vertical skirting round the edge forms a seal against the perimeter of the tank. **La Roche Frères, 46 rue Maries, Paris, X.**

BCE 824 for further information

Chemicals by Canal Boats

Canal carriers still have some spare space available in their boats, although, since the beginning of the fuel crisis, they have been busily engaged in meeting extra demands on their services. The craft vary in capacity from 25 tons (for a "narrow boat") to 400 tons or more. They are suitable for the transport of chemicals in bulk or packaged, and all may be covered as a protection against the weather. Details of available capacity may be obtained from **The National Association of Inland Waterways Carriers, Bridgewater Canal Office, Chester Road, Manchester, 15,** and **British Transport Waterways, 22 Dorset Square, London, N.W.1.**

BCE 825 for further information

Brine Testing Books

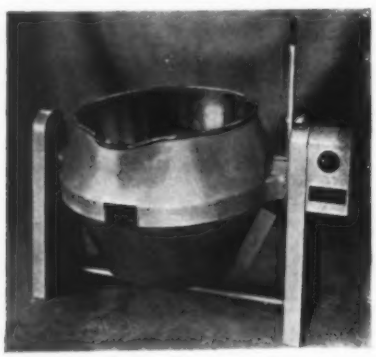
Books for the testing of the *p*H of brine are being made available in a pocket size (2 in. by 3½ in.) by A.P.V. Each book contains three booklets of papers covering the ranges *p*H 5.2 to 6.7; 6.8 to 8.3, and 8.4 to 10.0. Each book is sufficient for at least 20 tests. **The A.P.V. Co. Ltd., Manor Royal, Crawley, Sussex.**

BCE 826 for further information

An Electric-jacketed Tilting Pan

A tilting pan heated with an electric jacket is being made by the Stabilag Co. in conjunction with William Brierley, Collier & Hartley. It is intended for use in the food and confectionery industries or in plants that do not have adequate supplies of steam but that are served satisfactorily with electricity.

The prototype, which is illustrated, was designed with the co-operation of a firm of toffee manufacturers. At their suggestion the temperature gauge has been made very easily accessible and an adaptation has been incorporated to enable the heat input to be reduced when the boiling point of the contents have been reached. The consumption is slightly above 1 kW. The electricity supply is controlled by an energy regulator which operates from zero to full in-put. The manufacturers say that no insurance test is required before the pan is used, thinner-gauge materials may be used in it than in steam-heated pans, and it can be made in a portable form. The pan is single-cased and is not a welded fabrication. Special attention has been paid to providing the unit with a clean, neat appearance. A splash-guard is mounted round the pouring lip. All electrical and mechanical parts have been designed to be readily accessible. **Stabilag Co., Hemel Hempstead, Herts.**



BCE 827 for further information

An Oil Conditioner

Figure 832 oil conditioner has been added to the range of Bowser industrial equipment, now being manufactured in Britain by Liquid Systems. It is designed

to treat turbine or other low-viscosity oil, and it removes water from the oil, corrects any acid content and filters it. The operation is automatic, and the filter and dehydrating units, which are installed vertically in the machine, are easily removed for cleaning. The makers state that the power consumption is negligible and that there is no wear involved in its use. During processing, the oil is heated to reduce its viscosity so that the precipitation of solids and water can take place quickly. **Liquid Systems Ltd., Union Road, Croydon, Surrey.**

BCE 828 for further information

Axial-flow Fans

A range of axial-flow fans manufactured entirely from PVC materials has been made available by Horwitch Smith. The motors are on-line and are protected in a PVC housing which has been designed to offer minimum interruption to air flow. All electrical connections and windings are specially well insulated. The fan case is of welded Duoply laminate

construction, flanged at the ends for incorporation in the duct. The impeller, of rigid PVC, is built round a cast-aluminium core, and the body is removable from the motor housing. The motor is supported by a mild-steel ring bolted to the exterior of the fan case, and supported by three steel elongated tubes encased in PVC, which also act as breather ducts for the motor. **Horwitch Smith & Co. Ltd., Pensnett, Brierley Hill, Staffs.**

BCE 829 for further information

Pollution-removing Catalyst

The Oxycat catalyst-assembly, constructed for removing by oxidation the obnoxious constituents of industrial smoke, is being made in Britain by Oxy-catalyst. It consists of two end-plates, a tie-rod and a number of streamlined elements coated with a film of catalytic alumina and platinum alloy. The film is resistant to high temperatures. To start the catalyst reaction, the gaseous stream entering the unit must be at a minimum temperature of 500°F. Once started, the reaction itself will increase the Oxycat temperature until a state of equilibrium is reached. Normally a pre-heat burner is fitted ahead of the catalyst to assist in starting. Oxycat installations are effective for a wide range of combustible pollutants, including hydrocarbon solvents, sulphur compounds, ammoniacal fumes and carbon black. The Oxycat can also be used for the reduction of the oxides of nitrogen and for heat recovery. **Oxy-catalyst Ltd., Henley Park, Guildford.**

BCE 830 for further information

Asbestos Paint

Allweather Paints state that, as their latest product, Pitan Asbestos roof paint, is unaffected by free alkali in asbestos, it may be applied directly to new or old untreated asbestos roofs. The preparation, which is also resistant to acids, is available in the colours white, broken white and cream. **Allweather Paints Ltd., 36 Great Queen Street, London, W.C.2.**

BCE 831 for further information

Boiler Feed and Fuel Additives

A preparation for treating boiler-feed water is one of a new series of products being made available by the Industrial Chemical Treatments Division of Amber Pharmaceuticals. The makers say that it is suitable for use in boilers of all pressure ranges, is easily suspendable, con-

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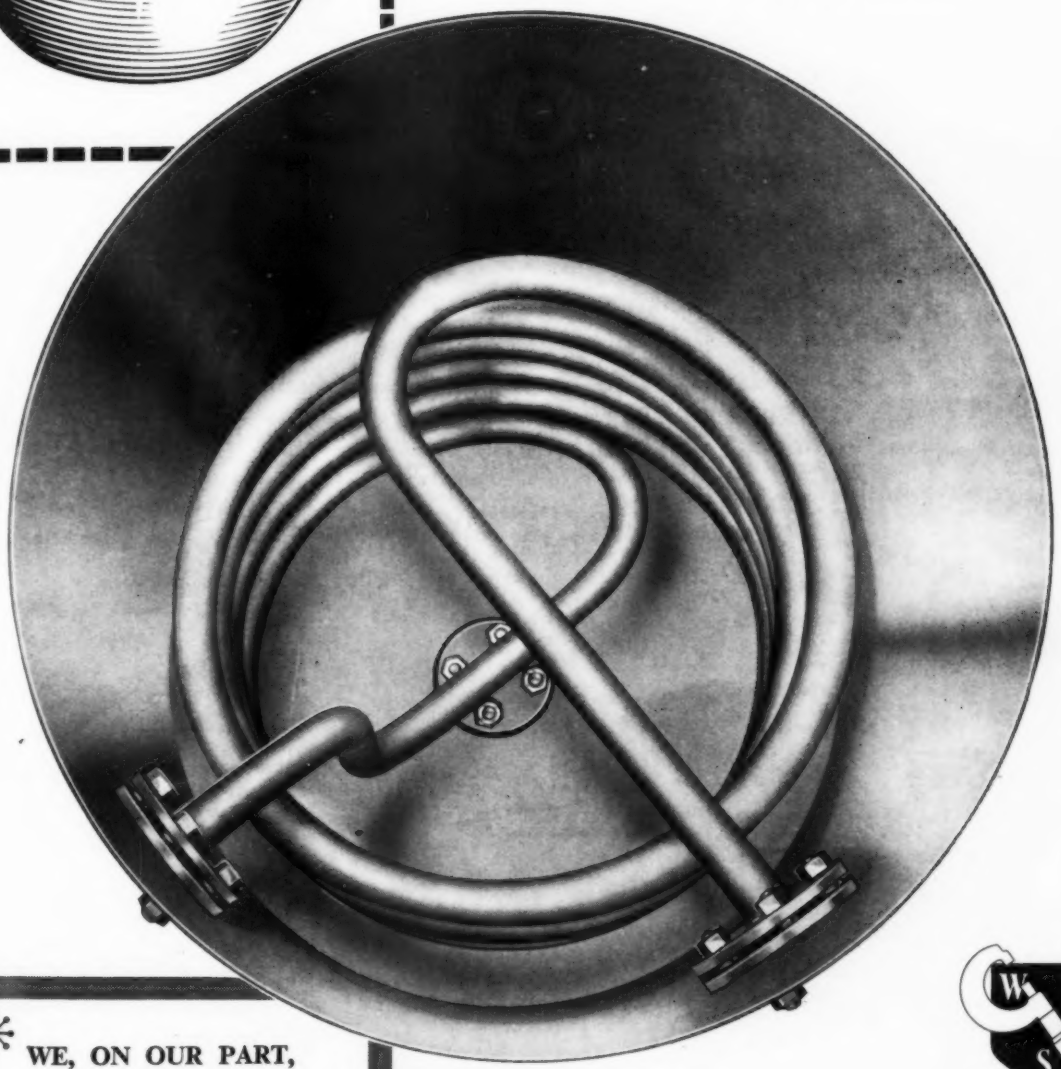

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PLANT EQUIPMENT NEWS

tains sequestering agents, phosphates and other *p*H correctors and a volatile correcting agent for condensate lines. The division is also marketing fuel additives for solid and diesel fuels designed to ensure complete combustion. **Amber Industrial Chemical Treatments Division, Amber Pharmaceutical Ltd., 11a Albemarle Street, London, W.1.**

BCE 832 for further information

Other Items of Interest

A new feature in the standard Dewrance consolidated safety relief valves, 1900 type, is the addition of an eductor tube. This allows pressure within the bonnet to be withdrawn into the discharge stream faster than it is possible for it to be applied through the guide clearance. Thus it ensures that only the force exerted by the spring controls the valve. **Dewrance & Co. Ltd., Great Dover Street, London, S.E.1.**

BCE 833 for further information

An industrial vacuum cleaner-and-blower having a weight of under 30 lb., and thus being suitable for "haversack" operation, has been developed by Bivac. The makers state that it is quieter than previous models, yet it has a 50% greater capacity. **Bivac Air Co. Ltd., Beehive Works, Portwood, Stockport.**

BCE 834 for further information

Alfred Bullows have introduced a tangential nozzle for spray guns in an endeavour to enable the maximum use to be made of energy of the activating air. The makers claim that, by using a tangential arrangement of the nozzle horns, the kinetic energy of the discharged air is used to the full, as the two air streams pass tangentially across the face of the nozzle. **Alfred Bullows & Sons Ltd., Long Street, Walsall, Staffordshire.**

BCE 835 for further information

Nylon nuts, in three colours for use in identifying different lines in the same plant, are being made by Talbot Stead. Before dispatch, the nuts are saturated with moisture so that no additional moisture can affect their dimensional stability. **Talbot Stead Tube Co. Ltd., Green Lane, Walsall, Staffordshire.**

BCE 836 for further information

The Pateena process for coating materials such as wood, metal and hardboard has been developed by Paripan. It is applicable to containers, instrument cases, etc., which are intended for use in tropical countries where they are likely to be subjected to the deleterious effects of heat and humidity and to insect and fungal attack. **Paripan Ltd., 1 Sherwood Street, London, W.1.**

BCE 837 for further information

New Publications

The British Standards Institution, 2 Park Street, London, W.1, has just issued two booklets entitled "Data on the Mechanical Properties of Steels at Elevated Temperatures". Booklet No 1 deals with wrought carbon steel, and booklet No. 2 with wrought 1% chromium, ½% molybdenum low-carbon steel. The data have been compiled by a technical committee that has been responsible for formulating British Standards on creep testing and determination of time to rupture. A Standard newly issued is part 2 of B.S. 2645 : 1956, "Tests for use in the approval of welders". It deals with manual metal-arc and oxy-acetylene welding of mild steel and low-alloy steel pipelines and pipe assemblies.

BCE 838 for further information

Two new publications on freeze-drying equipment have been issued by Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex. Leaflet E.186/3 describes the centrifugal freeze-drying units in their series 30, and brochure E.203/1 deals with the full range of the company's equipment, from the L5 unit for research work to model 51 for production-scale freeze-drying processes. Both brochures are abundantly illustrated.

BCE 839 for further information

Preliminary information on Bextrene, a polythene sheet extruded from toughened polystyrene granules, is given in an illustrated folder just published by B.X. Plastics Ltd., Higham Station Avenue, London, E.4. Also issued recently is a brochure reviewing the properties of Cobex thermoplastic synthetic material and its uses in constructions where resistance to corrosion is important.

BCE 840 for further information

"Nickel Plating for Engineers" is the title of a 72-page book just published by Mond Nickel summarising the considerations to be taken into account, chiefly by engineers, during the plating of metals with nickel. The text deals with the preparation of the metal surface; the various kinds of nickel-plating procedures; the mechanical properties of nickel deposits; the uses for nickel plating, including protection against corrosion and wear; the plant used for plating; and the testing of deposits. A number of data sheets are included. Copies are available from The Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1.

BCE 841 for further information

Catalogue 1056, just issued by Rhodes, Brydon & Youatt Ltd., Gorsey Mount Street, Stockport, is devoted to the company's new 350 Series of vertical high-temperature Mopump. Catalogue 1460, dealing with chemical process Mopumps, has been re-issued as a revised and enlarged edition under the code number 1460A.

BCE 842 for further information

Langley Alloys Ltd., Langley, Slough, Bucks, have issued a preliminary information sheet on their range of corrosion-resistant alloys Langalloy 20V. Among the information given are notes on composition, mechanical and physical properties, corrosion resistance and machinability.

BCE 843 for further information

A series of five catalogues has been issued by Hilger & Watts Ltd., Hilger Division, 98 St. Pancras Way, London, W.1, describing their apparatus for spectro-chemical analysis. Details of a number of new designs are included. Catalogue 1 deals primarily with general principles of spectro-chemical analysis and the others deal in turn with source units, photographic spectrographs, interpretation equipment, and direct-reading spectrographs. Each catalogue is liberally illustrated and the text is amplified by tables. The publications are numbered CH401 to CH405.

BCE 844 for further information

"Electronic Automatic Boiler Control" is the title of a forty-page catalogue issued by Evershed & Vignoles to replace their publication No. PL62. The catalogue is liberally illustrated with half-tone pictures, line diagrams, flow sheets and circuit diagrams. Copies may be obtained from the International Instrumentation and Controls Division of the company, Acton Lane Works, Chiswick, London, W.4.

BCE 845 for further information

A catalogue of industrial and protective clothing has been issued by Timeg Ltd., 338-341 Upper Street, London, N.1.

BCE 846 for further information

Newly prepared data sheets on the performance of the E.P.C. 1500 range of protective coatings against corrosion are available from Sandeman's Varnish Ltd., Murano Street, Glasgow, N.W.

BCE 847 for further information

Details of Beckman spectrophotometers and related instruments which are sold and serviced by Baird & Tatlock (London) Ltd., Chadwell Heath, Essex, are published in a new four-page illustrated brochure, copies of which are available from the company.

BCE 848 for further information

British Nylon Spinners have produced an informative folder of interest to chemical engineers entitled "Nylon for Filtration". The folder gives a brief outline of the many applications for nylon filter cloths in industry, and details some of its advantages over other methods of filtration, including costs. Copies may be obtained from British Nylon Spinners Ltd., Pontypool, Mon.

BCE 849 for further information

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These new pumps open up an extensive range of acids, alkalis and slurries to economical pumping. They are constructed in 18/8/3 Stainless Steel for mildly corrosive liquids or in WORTHITE, a super-resistance alloy steel enabling Sulphuric Acid to be pumped with negligible corrosion loss. Also, there is the added advantage of easy interchangeability of the Stuffing Box Packing with two types of Mechanical Seal to suit different processes — plus the embodiment of the well-known Worthington-Simpson "Monobloc" construction which means few parts, lower costs, less wear and easier installation.

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World of Chemicals

Michigan Fine Chemicals

A $300,000 plant for the manufacture of drug intermediates and fine chemicals is to be built at Muskegon, Mich., by a newly organised American firm, Ott Chemical Co.

Canadian Silicon Carbide

Canadian Carborundum Co. Ltd. has decided to enlarge its silicon carbide plant at Shawinigan Falls, Quebec.

Japanese Petrochemical Plans

Teikoku Oil Co. has applied to the Osaka Trade and Industry Bureau for permission to prospect and drill natural gas wells in a 93,000-acre area in the Lake Biwa region. If development is successful, the company will build ammonia and methacrylate resin units. Further plans are in hand for the production of ammonium sulphate and synthetic fibre.

East African Soap Factories

Companhia Industrial Portuguesa have been authorised to build a soap-making factory at Rio Monapo, Lumbo, Portuguese East Africa, and Maria Magarida de Senpa Rose has applied for permission to build a factory for the same purpose at Quelimane.

Canadian Aluminium Production

The capacity of the plants of Aluminium of Canada is being increased from 650,000 tons to 762,000 tons. The greater part of the increment will result from expansion of the plant at Kitimat, British Columbia. Production at the new hydroelectric plant at Chute des Passes, Quebec, will add 130,000 tons to the company's production when it commences operation in 1959.

Indian Synthetic Rubber

Plant for producing synthetic rubber components is to be built at Utter Pradesh and Rourkela, India. At the Pradesh plant alcohol available from sugar factories in the area will be used as a starting material for the manufacture of butadiene. Coke-oven gases will provide raw materials at Rourkela for styrene production.

Formosan Yeast Plant

A new yeast plant of the Taiwan Sugar Corporation at Hsingying, Formosa, is now in full production. It was built at a cost of N.T. $20 million and U.S. $800,000 from U.S. aid funds, has a capacity of 40 m.t. of yeast powder a day, and is claimed to be the largest plant of its kind in the world.

New Peroxide Process

A new catalytic method of manufacturing hydrogen peroxide is being used at the recently commissioned plant of Solway Process Division, Allied Chemical & Dye Corporation, Syracuse, U.S.A. Essentially, the process consists of a combination of hydrogen, obtained as a by-product from adjacent electrolytic chlorine plant, with atmospheric oxygen. Oxygen-containing complex organic materials are hydrogenated catalytically, and are then oxidised into a working solution containing hydrogen peroxide. The peroxide is extracted using a countercurrent flow of water, and the colution is evaporated to produce a concentrate containing 35 or 50% of peroxide. The original organic solution is re-cycled and used again.

German Chemicals Output

During the first nine months of 1956 the turnover of the German chemical industry rose by 8% over the figure for the corresponding period in the previous year. The increase compares with 14% in the period 1954-55. The turnover during the nine months in 1956 was D.M. 1,100 million. Exports in the first half of the year were worth D.M. 1,820 million, of which 62 6%was taken by European countries, particularly Holland, France and Italy, compared with 59.5% in 1953, when these exports first became substantial. The gains in Europe during the first half of 1956 were offset by lower exports to Africa—particularly in sales of potash fertilisers to Egypt—and Asia. Hong Kong, China and Korea took fewer German chemicals, although exports to Indonesia, Iran and India increased. Trade with North and South America remained favourable.

Indian Developments

The Indian Union Government has decided to undertake the manufacture of intermediates required for the manufacture of dyestuffs, drugs, plastics and explosives. The plan will be developed by the National Industrial Development Corporation at a cost estimated at Rs. 18 crores. The Government is also considering a plan for the manufacture of optical glass, and interest in the project has been expressed by the United Kingdom, the U.S.S.R. and the German firm of Zeiss.

Dutch Manufacture of Synthetic Resins

Synthetic resins are to be manufactured in Holland jointly by the Dutch plastics manufacturer, Scado (Zwolle), and Archer-Daniels-Midland Co. of U.S.A. under a recently concluded agreement.

Shell's German Expansion

Between £50 million and £60 million are to be spent on new plant by Shell in Germany. Three large projects for the organisation are under way, or about to be started, and a refinery with an annual throughput of 3 million tons of crude oil is to be built at a cost of £25 million between Bonn and Cologne. The plant is to be ready by 1960-61, but subsequently it may be expanded to double its capacity. The throughput capacity of Shell's Hamburg refinery will be raised at a cost of £25 million from 0.9 million tons to 2.8 million tons. Work on the extensions has started and is to be completed by the summer of 1958. The olefin petrochemical works near Bonn is to be greatly expanded at a cost of £12 million to £13 million, which will be borne jointly by Shell and Badische.

U.S. Research

A three-year programme of fundamental research on free radicals has been undertaken by the U.S. National Bureau of Standards, with the object of increasing knowledge of the formation, properties and storage of these highly reactive molecular fragments. A technical data centre is being established so that research on the subject at other laboratories, in the United States and abroad, may be followed.

The effect of ceramic coatings on the creep rates of alloys under stress at high temperatures has been studied recently by the Bureau. Results indicate that, although under some conditions a coating can reduce the creep rate as much as 50 per cent, under other conditions a deleterious effect is produced. The investigation was carried out by J. R. Cuthill, J. C. Richmond and N. J. Tighe and their results are to be published in the *Journal of the American Ceramic Society*.

The Bureau has developed a non-destructive procedure for ascertaining the size and position of pores, which involves photographing an electroplated specimen exposed to radiation. It detects pits, voids and inclusions in the coating to the order of 0 001 in. in diameter. Discontinuities in the basis metal may also be determined by radiographing the metal before plating.

Czech Pharmaceuticals Production

Since 1949 production of pharmaceuticals in Czechoslovakia has risen fivefold. The principal products include sulphonamides, barbiturates, phenothiazine, sodium para-amino salicylate and steroids.

German Polyethylene Production

The annual output of polythene, known in Germany as Lupolen H, from the Rheinische Olefinwerke, Wesseling, near Cologne, is to be raised from 10,000 tons to 35,000 tons during the next three years.

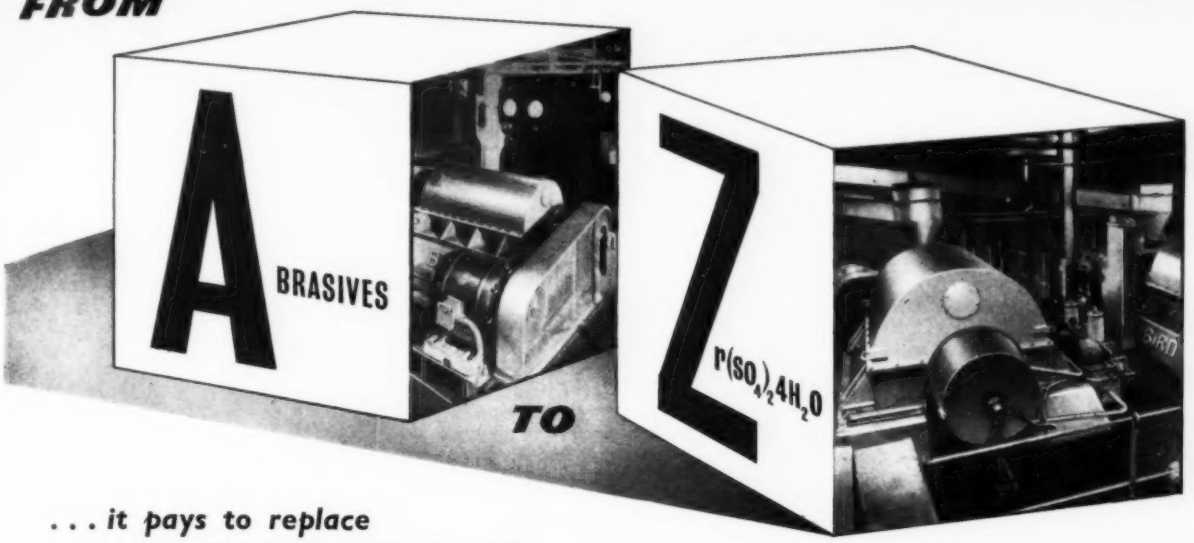
Expanding Italian Production

During the first seven months of 1956 mercury exports from Italy increased to 1722 tons against 583 tons during the same period of 1955. Sulphur production during the first six months of 1956 was 96.804 tons, of which 54,964 were exported.

Portuguese Chemical Industry

Recently the Lisbon firm SOCINO (Sociedad Industrial Quimica Opoterapica S.A.R.L.) was formed to manufacture raw materials for the pharmaceutical industry, especially liver extracts. The Belgian-controlled Soda Povoa S.A.R.L., Provoa de Santa Iria, has begun to manufacture trichlorethylene near Lisbon.

FROM



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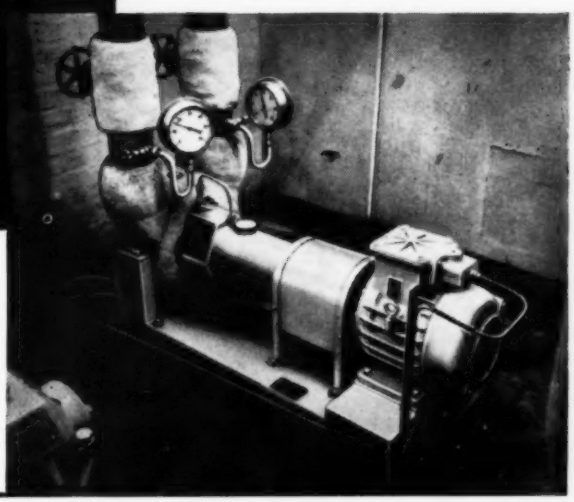

Illustrated here is a 310.L type 'CP' Mopump with water-cooled bearing housing and stuffing box, handling 1800 gallons per hour of Tetra-aryl Silicate at 615°F. At the Ardeer factory of Imperial Chemical Industries Limited (Nobel Division)
(Contractors: Hygrotherm Engineering Limited).

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BCE 771 for further information

The Month's News in Brief

The chemical and allied industries are leading all others in capital expenditure that is expected to be made during the year 1957, as compared to that of 1956. Expenditure in plant machinery and vehicles will be increased in these industries by 26% and on building work by 6%. The total increase will be 29%. Iron and steel is the industry with the next highest expenditure. The total is 15% and includes an increase on plant, etc., of 18% and a decrease of 7% on building work. The third highest expenditure is being made by the non-metalliferous mining products industry (+7% on plant; +14% on building; total +9%). For all manufacturing industry the figures are: plant and machinery, +3%; building, −7%; total +1%.

A significant transfer of ownership in the field of chemical engineering was completed in London during December.

The president of the Electric Bond and Share Company of New York, Mr. George Walker, and his vice-president, Mr. Lester Ginsburg, recently visited London in connection with the formation of a new company, Chemical Construction (Great Britain) Ltd. This company has absorbed the former engineering division of the American-owned Cyanamid Products Ltd., of London, whose personnel, with twenty years' experience in constructing plants throughout the sterling area, has also been taken over.

The big London take-over was duplicated some months ago in the U.S., when the Chemical Construction Corporation, also formerly owned by the American Cyanamid Company, was acquired by Electric Bond.

Managing director of Chemical Construction (Great Britain) Ltd. is Mr. Michael S. Henderson. For many years and until the end of 1955, Mr. Henderson was director of Cyanamid Products Ltd., in Britain, which company was responsible during the war for the construction of many plants vital to the war effort. Three other directors have been named as members of the new company's board. They are Mr. H. W. J. Smiter, director and chief engineer; Mr. Carpenter, president of Ebasco Services Incorporated, a co-subsidiary of Electric Bond; and Mr. Harwick, a vice-president of the U.S. Chemical Construction Corporation.

The United Steel Cos. Ltd. are to establish a new central department of operational research and cybernetics. Based in Sheffield, the department will serve all the branches of United Steel with advice and recommendations on operational research problems, and will provide the personnel to carry out its proposals. Because the whole concept of operational research is itself relatively new, it will also conduct its own research projects and initiate training schemes for those joining its staff.

Mr. Stafford Beer, formerly production controller at Samuel Fox & Co. Ltd., a United Steel subsidiary, will head the new department. He will work under the general direction of Mr. S. R. Howes, a director of United Steel.

I.C.I. are to increase production of "Terylene" polyester fibre to 30 million lb. a year by extending sections of the "Terylene" plant at Wilton in North Yorkshire. Work will begin in the spring of 1957, and additional quantities of "Terylene" will become available early in 1959.

Formalities have been completed for the purchase by Tube Investments Ltd. of the whole of the share capital of Bennett Tools Ltd., of Redditch, high precision engineers. Mr. R. Bennett, the founder of the business, will continue as its managing director. Mr. E. L. Burton and Mr. R. D. Young, of Tube Investments, have joined the Board.

Q.V.F. Ltd. have moved from Mill Street, Stone, Staffs. to Duke Street, Fenton, Stoke-on-Trent. Telephone: Longton 32104.

Air Control Installations Ltd. have moved their Birmingham office, owing to continued expansion of business, to Wolverley House, Digbeth, Birmingham, 5. Telephone: MIDland 5148.

Solway Flowrators Ltd. have changed the name of the company to Fischer & Porter Ltd. The reason for the change is that the company is now a 100% subsidiary of Fischer & Porter, of Hatboro, Pennsylvania, U.S.A. The company intends to embark upon a manufacturing programme of process control equipment and variable area flow meters which will greatly extend their present range of products.

Brook Motors Ltd.'s Newcastle sales office was moved to larger premises on January 8. The new address is 6 Archbold Terrace, Newcastle upon Tyne. Telephone: Newcastle 81-1003.

Acknowledgement is due to Wellington Tube Works Ltd. for permission to reproduce the lower illustration on p. 411 of the December issue of *British Chemical Engineering*. This showed an example of expanded tube construction. Acknowledgement is also due to G.E.A. Luftkuhler-Gesellschaft m.b.h. for permission to publish the illustration on p. 32 of the January issue of *British Chemical Engineering*.

Atomics

To establish a permanent means of liaison between different sectors of the engineering industry on matters relating to nuclear energy and associated developments, the Nuclear Energy Trade Associations' Conference (NETAC) has been formed.

Founder members of NETAC, all of which are closely connected with the field of nuclear energy, are: British Chemical Plant Manufacturers' Association; British Electrical and Allied Manufacturers' Association; British Engineers' Association; Scientific Instrument Manufacturers' Association; and Water-Tube Boilermakers' Association.

Present chairman is Mr. W. K. G. Allen (W. H. Allen Sons & Co. Ltd.), president of the British Engineers' Association, whose staff serve as the Secretariat for NETAC. The address of the Nuclear Energy Trade Associations' Conference is that of the British Engineers' Association, 32 Victoria Street, London, S.W.1.

The Atomic Energy Authority has set up a Commercial Department within its Industrial Group to handle sales of uranium, plutonium, thorium, graphite and other similar materials for the Authority. Within the general policies laid down by the Authority, this department will be responsible for negotiating terms and conditions of sale, including the determination of selling prices.

The manager of this department is Mr. W. P. Warren, whose address is U.K. Atomic Energy Authority, Industrial Group Headquarters, Risley, near Warrington, Lancs.

The Japanese Ministry of International Trade and Industry has elaborated a new process for the refining of uranium ores of poor quality. It is called an evaporation method, and in its use, pulverised ore is heated to between 700°C and 800°C in a furnace, and is then subjected to a blast of chlorine and carbon monoxide. Uranium is extracted from the resulting uranium chloride vapour electrolytically. The method is undergoing further tests.

Work on the first atomic reactor to be built in Czechoslovakia is under way at a site near Prague. Building on associated constructions, such as the water tower and boiler-house, is in the first stage.

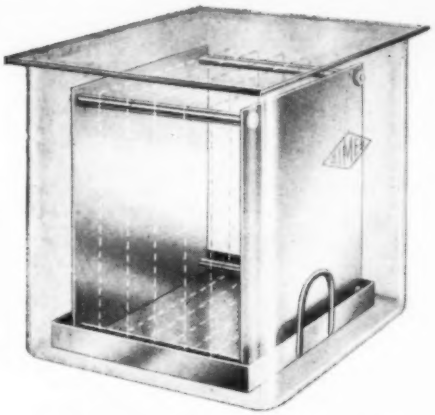
India's first nuclear power station is likely to be set up before the end of the second five-year plan, in 1960-61, according to a recent statement by Dr. Homi I. Bhabha, Secretary of India's Atomic Energy Department. The power station will be largely of foreign design and make, but considerable portions of it may be made in India. The Atomic Energy Establishment at Trombay, Bombay, will be provided with facilities for developing power stations of Indian design, and, within the next 18 months a number of uranium processing plants will be set up in the country.

The Swedish Atomic Insurance Pool was formed in Stockholm at a recent meeting of Sweden's leading insurance companies. The activities will include insurance and re-insurance both in Sweden and abroad of plant for producing atomic energy in all its different stages. Mr. G. Kalderén, of the Skandia Insurance Company, was elected Chairman of the Pool.

People In The News

Sir Andrew McCance, chairman and managing director of Colvilles Ltd., succeeded **Sir Ernest Lever**, chairman of Richard Thomas & Baldwins Ltd., as president of the British Iron and Steel Federation on January 1. The federation council also appointed **Mr Gerald Steel**, general managing director of the United Steel Companies Ltd., president-elect.

Sir William Owen, director of engineer-



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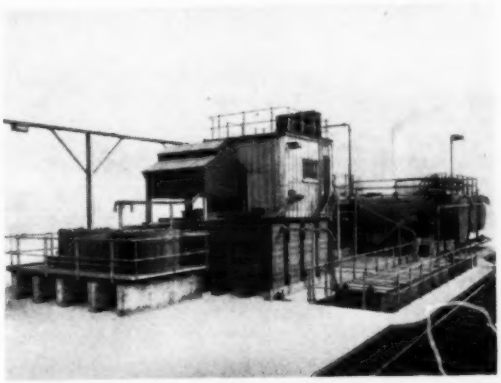

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E. J. Sturgess, *chief engineer of Shell Petroleum Co. Ltd., who has been awarded a C.B.E. in the New Year Honours.*

ing, United Kingdom Atomic Energy Authority's Industrial Group, one of the recipients of New Year Honours, is the subject of a note in "Digest". Other honours announced in this year's list include:

Knights Bachelor: **D. S. Anderson,** director, Royal College of Science and Technology, Glasgow; **J. Eccles,** deputy chairman (operations), Central Electricity Authority; **F. G. C. Fison,** chairman, Fisons and other companies, for political and public services in Suffolk; **F. J. Pascoe,** chairman and managing director of British Timken and other companies, for political services; **C. P. Snow,** commissioner and scientific adviser, Civil Service Commission.

Order of the Bath, Civil Division: **B. K. Blount,** deputy secretary, D.S.I.R.

Order of Merit: **Sir John Cockcroft,** director, A.E.R.E.

Royal Victorian Order, G.C.V.O.: **Brigadier-General Sir Harold Hartley,** president, World Power Conference; former president, British Association for the Advancement of Science, and past president of the Institution of Chemical Engineers.

Order of the British Empire, G.B.E.: **Sir Archibald Finlayson Forbes,** chairman, Iron and Steel Board. *K.B.E.:* **Sir Christopher Hinton,** member of the Board, U.K. Atomic Energy Authority. *C.B.E.:* **A. Barclay,** keeper, Science Museum; **C. M. Cawley,** deputy chief scientific officer, D.S.I.R.; **S. Cahn,** managing director, Goodlass Wall & Lead Industries Ltd.; **A. T. Green,** director of research, British Ceramic Research Association; **O. W. Humphreys,** director, General Electric Co. Research Laboratories; **E. J. Sturgess,** chief engineer, Shell Petroleum Co. Ltd. *O.B.E.:* **W. Barr,** technical director, Colvilles Ltd., Glasgow; **F. G. Brewer,** secretary, The Gas Council; **C. Bride,** inspector of alkali and works, Ministry of Housing and Local Government; **J. W. Christelow,** senior principal scientific officer, National Physical Laboratory, D.S.I.R.; **H. Kronberger,** chief physicist, Research and Development Branch Headquarters Industrial Group, United Kingdom Atomic Energy Authority; **A. Mathisen,** managing director, Graviner Manufacturing Co. Ltd.; **A. E. Roots,** area manager, South of Scotland Electricity Board.

W. Worboys, commercial director, I.C.I., and chairman of the Council of Industrial Design, has received the Royal Society of Arts Bicentenary Medal for his part in promoting the development of art and design in British industry.

The following awards of Institute of Metals' Medals have been announced: *The Institute of Metals (Platinum) Medal for* 1957. To **Dr. Maurice Cook,** joint managing director, Imperial Chemical Industries Ltd., Metals Division, in recognition of his outstanding contribution to the science of metallurgy, to the non-ferrous metals industry and to the welfare of the metallurgical profession. *The Rosenhain Medal for* 1957. To **Dr. H. K. Hardy,** research manager, United Kingdom Atomic Energy Authority, Industrial Group, in recognition of his outstanding contributions to knowledge in the field of physical metallurgy.

Sir Miles Thomas, in addition to his post as chairman of Monsanto Chemicals, has become chairman of a new firm of industrial consultants, Mead Carney & Co.

Mr. C. E. Evans, previously general manager of British Hydrocarbon Chemicals at Grangemouth, has been appointed general manager of the company. **Mr. D. Blair Watt** has been appointed works general manager at Grangemouth.

Dr. G. L. Riddell, director of research at the Printing, Packaging and Allied Trades Research Association since its formation 26 years ago, is to relinquish this post on March 31. He is to join Albert E. Reed & Co. Ltd. as head of their packaging research and development division.

Dr. Alexander King, *who has been appointed deputy director of the European Productivity Agency. Previously he was a Chief Scientific Officer in the D.S.I.R.*

Dr. Ronald Holroyd, director in charge of research, has been elected a deputy chairman of I.C.I. in place of **Mr. A. J. Quig,** who has retired after nearly 50 years' service with the company and its predecessors. There are two other deputy chairmen—**Mr. S. P. Chambers** and **Sir Ewart Smith.** Dr. Holroyd, who is 52, is a Yorkshireman. Educated at Archbishop Holgate's Grammar School, Barnsley, he read chemistry at Sheffield University, where he gained his M.Sc., and did research in fuel technology. He joined I.C.I.'s Alkali Division in 1928, and four years later moved to Billingham, where he became closely associated with the development of the oil works. From oil research manager in 1936, he rose to divisional research director in 1947. In 1951 he became joint managing director of the Billingham Division. During his later years at Billingham he was largely concerned with the production of petrochemicals. In the closing stages of World War II he led a number of teams investigating German oil and aviation fuel developments. Dr. Holroyd was appointed to I.C.I.'s main board in November, 1952, and became research director in May, 1953. Dr. Holroyd is also chairman of the D.S.I.R.'s Food Investigation Board and was previously a member of their Fuel Research Board. His many other activities include membership of the Colonial Products Council, the Science Museum Advisory Council

Mr. J. Ornstein, deputy chairman and managing director of B.P.'s German associated company, has been appointed an honorary Commander of the Order of the British Empire (C.B.E.) for services to the British community in Germany. Mr. Ornstein, who is French, has had 44 years' service with the oil industry, most of it with the B.P. Group in France and Germany. After the last war he became B.P.'s representative in Germany and managing director of the German company.

Three changes have been made in the board of Dyestuffs Division of I.C.I. **Mr. S. Howard,** formerly division joint sales director, has been appointed division managing director jointly with **Mr. H. Jackson** and **Mr. H. Smith. Dr. H. Samuels,** formerly joint deputy north regional manager, has been appointed division home sales director. **Mr. R. M. Gibb,** formerly head of Dyestuffs Division Distribution Centre, has been appointed a division director in charge of Commercial Services.

Mr. Frank Rowe has been appointed a director of The George Cohen 600 Group Ltd.—the holding company which controls the 600 Group. Since 1943 Mr. Rowe has been managing director of one of the largest companies in the 600 Group—K. & L. Steelfounders and Engineers Ltd. He will continue to hold this position.

The president of the Royal Society, **Sir Cyril Hinshelwood,** has appointed the following vice-presidents for the year ending November 30, 1957: **Sir David Brunt, Professor G. L. Brown, Sir Claude Gibb** (chairman and managing director of C. A. Parsons & Co. Ltd.) and **Sir Bryan Matthews.**

Two new sales appointments have just been announced by the Chloride Group of companies. **Mr. T. Dawson** has taken up the new post of group export sales manager and will, in addition, be responsible for commercial liaison with the group's overseas associate companies. **Mr. P. C. Aspinall,** who was assistant export manager under Mr. T. Dawson, becomes the new export manager for Chloride Batteries Ltd. in succession to Mr. Dawson.

Dr. Albert Parker, Director of Fuel Research in the D.S.I.R. since 1943, retired on December 31, 1956, after 28 years' service with the Department. He joined the Department as assistant director of Water Pollution Research in 1928 and was director of Water Pollution Research from 1939 to 1943. He previously held university and industrial appointments. The Council for Scientific and Industrial Research has appointed Dr. A. C. Monkhouse to be acting director of Fuel Research. Dr. Monkhouse is at present the deputy director of Fuel Research.

G. & J. Weir Ltd. have appointed **Mr. Luke Fraser** as their London manager. Mr. Fraser was previously their Scottish sales representative and this position will now be filled by **Mr. Forrest T. Randell** from Cardiff branch office. **Mr. A. C. Smith,** former London manager, has now returned to the head office in Glasgow as sales director.

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